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THE

IRON ORES

OF

GREAT BRITAIN AND IRELAND

THEIR MODE OF OCCURRENCE, AGE, AND ORIGIN AND THE METHODS OF SEARCHING FOR AND WORKING THEM

WITH A NOTICE OF SOME OF THE IRON ORES OF SPAIN

BY

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With Numerous Illustrations

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PREFACE.

THE object I have had in mind in producing this book has been to give a systematic and careful account of our present knowledge of the origin and occurrence of the Iron Ores of Great Britain, and of the means of reaching and working such ores. I have given also a brief account of the early working of the ores in this country. A considerable amount of practical information is introduced with reference to some of the more important ores of Spain. A book covering this ground will, I conceive, meet a very great want—a point which will surely not need urging in view of the vast importance of our Iron industries, and of the fact that the published information of the last thirty years, relating to the Ores of that metal, can only be found by a laborious search through the "Transactions" of a number of scientific bodies; while even then it is only an imperfect and interrupted view of the subject which is obtainable.

The present volume should, therefore, prove useful

to all who are practically interested in the Iron Ores of this country, whether from the commercial or the scientific standpoint; and it is hoped, moreover, that it will be of service to those who are engaged in searching for or working such ores in other countries. In fact, having myself examined many deposits of different kinds in various parts of the world, I feel very sure that this will be the case.

It will be observed that all the Ores noticed in the book are not treated with equal fulness, preference having been given to those of the greatest commercial or scientific importance, so as to keep the volume within moderate limits.

It may be added that the facts relating both to the geology and the mining of the ores, which are set out in the work, have been derived almost entirely from my own observations, as I have had special opportunities, during the last thirty years, of becoming acquainted—more or less intimately—with every description of Iron Ore deposit within the United Kingdom.

WHITEHAVEN,
January, 1893.

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ERRATA.

Page 131, Fig. 19, second line of *References* : "churns at. Limonite" *should read* "churns of Limonite."

Page 133, line 8 : "hanging wall" *should be* "footwall."

Page 199, heading of second column of Table : "Metallicerin" *should be* "Metallic Iron."

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in the United Kingdom.

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INTRODUCTION.

TO its immense stores of iron and coal Great Britain probably owes as much of its supremacy as it does to its insular position or to the race-characteristics of its people. Had we been placed in a country entirely devoid of either iron or coal the whole course of recent history would have been changed. Our railways and steam-engines, with all that depend on them, and the enormous revolution they have effected in the social, commercial, and scientific worlds, might still have been but possibilities of the future.

There is probably no piece of country in the world, of equal area, which possesses such enormous resources of coal and iron as Great Britain; but, owing to the peculiar character of our mineral laws, we work at a great disadvantage compared with other nations. Our system of royalties and way-leaves is a serious hindrance to working, especially of inferior deposits. Even rich deposits, however, can scarcely be worked profitably in times of dull trade. The imposition of high royalties is injurious not only to lessees and the nation at large, but to lessors as well, for the simple reason that a lessee, working under difficulties, will only take the most easily obtained mineral, leaving behind him, at times, enormous quantities to be lost, most probably, to the lessor, the nation, and the world.

Another branch of the same question is the locking up of mineral properties so that they cannot be worked. This is even more a national matter than the one of royalties, for the nation alone can deal with it. Mining adventurers may refuse to take a property on terms which they consider prohibitory, but they cannot compel a landlord to let them any particular property which he does not wish to have worked, or which he is withholding from the market for the purpose of enhancing its value at some future date. The nation, however, can do this; and if we are to maintain our own, in the struggle for existence, it will have to be done. The writer knows of many properties containing deposits of iron ore which are locked up in this way, to the great detriment of the districts in which they lie, and, of course, to the nation's loss as well. In this respect tenants are as much to blame as landlords, for they frequently hold, unworked, for years, large tracts of land which, if worked, would add greatly to the country's wealth.

Then there is the question of letting down the surface. It is impossible to work profitably many deposits of iron ore without actually destroying the surface for agricultural purposes. But as the law now stands, a mineral lessee cannot in some cases do this; in other words, he cannot work his minerals without the consent of the surface owner, if the ownership of the minerals and surface is divided. Here, too, the law needs amendment, for the consent of the surface owner can only be obtained, at present, by payments out of all proportion to the value of the land injured.

It is to be hoped that the work of the Royal Commission on Royalties will not be thrown away, but that some, or all, of the matters above alluded to may be speedily rectified by parliamentary interference. The writer has, however, doubts, for he has very little confidence in the method employed by Royal Commissions for arriving at the whole truth. Cross-

examination by persons representing opposing interests alone can do this. True, the Royal Commission on Royalties is constituted so that the various conflicting interests may be heard; but the local knowledge of each member is necessarily limited, and therefore a witness may tell as much, or as little, as will suit his own case; and the Commission have no means whatever of knowing whether he has told the whole truth. Cross-examination of witnesses by persons other than the Commissioners would bring out much that, in the present system, might be suppressed. The writer knows of, at least, one case, before the recent Commission, in which a witness would have told a very different story if he had been cross-examined by some one from his own neighbourhood.

Another matter of urgent importance for the economical utilisation of our iron resources, is that those engaged in the management of mines should have a more thorough knowledge of the nature of irregular ore deposits than they very frequently have. It is really lamentable to see the way in which money is often wasted in searching for these deposits in situations where a fuller knowledge of stratigraphy and of the nature of mineral deposits would have shown there was not the remotest chance of finding them. In these days of technical and scientific education, surely it is not too much to ask that those charged with the direction of mineral explorations should understand at least the elements of their work. It would, however, surprise the public to know how often this essential knowledge is wanting, even where one might reasonably expect it ought to exist. In many cases, however, it is not to be expected. Men are taken from the office or the shop, and put in charge of technical operations of the most complicated character, without the least previous preparation. Having spent nearly thirty years in practical mining in various parts of the world, and in mineral deposits of different kinds, the writer

has not the least hesitation in saying that the acquirement of anything like an accurate practical knowledge of irregular deposits is the most difficult subject with which the mining engineer has to deal; and yet how often do we find the difficulty entirely ignored, with the natural result, that the cost of exploring is increased enormously. The interest and redemption of money thus wasted amounts practically to another royalty, one, however, which the mining public can free themselves from, without the intervention of Parliament, once its true character is realised.

PART I.

HISTORICAL AND STATISTICAL NOTES.

THE IRON ORES OF GREAT BRITAIN.

CHAPTER I.

INTRODUCTORY.

It is impossible to write anything like a complete history of the working of iron ore in the British Isles, for unfortunately (but as always happens when it is necessary to look far back into the past), the "first beginnings" are lost in the thickening haze of time; and even in the nearer prospect but a very imperfect view is obtained. In this case, however, the importance diminishes as the backward time increases, so that there is less reason than often exists for regretting our inability to open out the past. To fill in the gaps between points that may be somewhat distinctly observed in the prospect by mere conjecture, although it might present upon the whole a unifying and pleasing result, could not possibly produce a true picture. All, therefore, that will be attempted here is an outline delineation of some of those features which are most clearly discernible. In doing this, it may be useful to look first at some of the more salient points in the development of the Iron trade generally, before taking the different iron-ore-producing districts in detail.

It can scarcely be doubted that charcoal was the fuel used in making iron prior to Dudley's discovery of producing it with coal in 1618, and, even after that date, charcoal appears

to have been principally used until Darby's discovery in 1735, owing to the want of success up to that time attending the manufacture of iron with coal; for Dr. Plott,[1] writing in 1686, says: "The last effort that was made in this country for making iron with pit coal was with raw coal by a Mr. Blewstone, a German, who built his furnace at Wednesbury." This last experiment is said to have been conducted with raw coal; but that was not because they were ignorant of the method of coking, for Dr. Plott further says: "They have a way of charring the coal in all particulars the same as they do wood. The coal thus prepared they call cokes, which conceives as strong a heat almost as charcoal itself, and is as fit for most uses but for melting, fining, and refining of iron, which it cannot be brought to do, though attempted by the most skilful and curious artists."

This exclusive use of charcoal led to great destruction of timber in all parts of the country where iron was found, and we, in consequence, meet with numerous Acts of Parliament prior to Dudley's time, prohibiting in certain areas the use of timber for iron-making, and even the erection of ironworks. So long as charcoal only was used in iron-making it was impossible there could be any considerable expansion of the iron trade, as the quantity of timber was necessarily so very limited, and, as a result, we find that in those early days iron was largely imported from abroad. The difficulty, however, in the use of coal, alluded to by Plott, was at last overcome by Abraham Darby at Coalbrookdale in 1735. Since then the remarkable development of the iron trade is briefly indicated by the following table:—

Year.		Production of Iron in Great Britain. Tons.
1740.	... ...	17,350
1760.	—Smeaton's improved blowing engine first erected at Carron.	
1783. 1784.	—Patents granted to Cort for puddling and rolling iron.	

[1] "Natural History of Staffordshire."

Year.	Production of Iron in Great Britain. Tons.
1788.	61,300
1788.—Watt's improved steam-engine began to be used in iron-making.	
1796.	125,079
1801.—Blackband ironstone of Scotland discovered.	
1806.	243,851
1823.	455,166
1829.—Hot-blast introduced by Neilson.	
1830.	677,417
1839.	1,248,081
1842.—Iron beginning to be used in shipbuilding.	
1844.—Commencement of railway mania.	
1847.	1,999,608
1851.—Cleveland ore commenced to be worked extensively.	
1852.	2,701,000
1852.—Northamptonshire ore commenced to be worked extensively.	
1856.—Bessemer announced the success of his method of steel-making.	
1865.	4,825,254
1880.	7,749,233
1890.	7,904,214

For the last fifteen or sixteen years an increasing quantity of ore has been imported from Spain—amounting in 1890 to about 3,000,000 tons—and an insignificant quantity from North Africa, otherwise the enormous production of iron shown above has been obtained from native ores.

Having glanced at the progress of the iron trade generally, let us next look at it more in detail, so as to obtain some idea of its rise and progress in the different parts of the country.

CHAPTER II.

THE EARLY WORKING OF IRON ORES.

Cumberland. It is quite uncertain when hæmatite was first worked here; but it can scarcely be doubted that the hæmatite veins of the Lake District mountains attracted attention before the more important deposits now being so extensively wrought in the carboniferous rocks; for the simple reason that the mountain veins are so much more easily found, being in many cases plainly seen on the surface. On the other hand, the carboniferous rocks are, generally speaking, obscured by a covering of glacial matter, which varies in thickness from a few feet to more than twenty-five fathoms; so that the hæmatite deposits in them, even when not overlain by solid rock, would only be found by digging through the glacial deposits; an operation for which in early days, except where thin, there would be little need.

In nearly all the valleys of the Lake District there is indirect evidence of the early working of iron ore. Heaps of iron slag occur by the side of almost every stream of any importance in the neighbourhood of iron ore. Some of these, the history of which is unknown, may be seen by the side of Whiteoak Beck, near Lowes Water; at the foot of Smithy Beck, Ennerdale; by the river Calder, near Thornholme; by the side of the Irt, near the Strands; and at the foot of Wastwater, as well as in Eskdale. The fact of these slag heaps being in such positions would seem to indicate that they belong to a period subsequent to that of the wind-furnace or even its immediate successor—the furnace urged by hand-

bellows, or their equivalent—and that they may fairly be allocated to the time when, by the operation of that universal process in nature which secures the survival of the fittest, machines urged by manual labour gave place to more powerful machines impelled by water. This was the last stage passed through in the evolution of the means of blowing iron furnaces, prior to the utilisation of the steam-engine for that purpose; so that, although, as is well known, mechanical appliances of the ruder kind (like low biological forms) frequently persist through great lengths of time, yet it is quite possible that these slag heaps may not take us so far back as do the written records to be hereafter noticed.

The earliest working of which any account seems to have been preserved was at Egremont, or perhaps it would be more correct to say in Egremont parish, for, as will hereafter appear, it is probable that Bigrigg was the place referred to. From the Chartulary of the Abbey of Holme Cultram, it appears that William, the third Earl of Albemarle, who died in 1179, gave to that abbey a forge at Wynefell (Whinfell) and an iron mine at Egremont.[1] As mentioned above, this was probably at Bigrigg, in the parish of Egremont, and only about a mile from the town of that name. Iron ore is now being worked at Egremont, but it is under a considerable thickness of glacial drift, so that it is most unlikely any of it would be known in the twelfth century; at Bigrigg, however, the drift covering is, in places, very thin. Moreover, it is certain that iron ore was worked in that locality at an early date, as will presently appear.

From information supplied by Mr. Clutton to the late Mr. H. Fletcher,[2] it appears that iron ore was worked, more or less interruptedly, at Bigrigg, from 1635 to 1701. In the stewards' and receivers' accounts, etc., of money accompted for Egremont iron ore, the first entry is for "Ore gotten at Nicholson Pitts from March 30th, 1635, to Michas. 1638."

[1] Dugdale's "Monasticon."

[2] "Archæology of the West Cumberland Iron Trade," by H. Fletcher. *Transactions of Cumberland and Westmoreland Antiquarian and Archæological Society.*

There is not any amount attached to this item. In 1643 the sum of 17*s.* 7*d.* was received as royalty, and from 1644-48 a few pounds each year. Until 1667 there do not appear to have been any further raisings, but in that and the ten years following the annual receipts were from £50 to £100, and from 1679-1701 inclusive they ranged from £200 to £350, with the exception of 1688, 1693, and 1699. In the two first of these years there were not any receipts, and in the last year they amounted to £452 15*s.* The royalty was 5*d.* per ton; so that in the year 1699 the output must have been 21,732 tons. One of the partners in this undertaking was Mrs. Ann Hebar, whose name is first mentioned in the accounts in 1682. Another partner was Thomas Addison, Esq., his name first appearing in the accounts in 1693. These pits are probably those referred to by Mr. Thoresby in his diary September 7th, 1694, wherein he says that near Egremont he passed "by the iron mines where we saw them working, and got some ore." They were evidently the same pits referred to by Robinson[1] in 1709. He says: "In a place called Langhorn, within that manor (Egremont), is a belly or a pipe of iron ore eight yards deep, in breadth eighty yards and in length one hundred yards, out of which several thousand tons were yearly got, many years last past; the ore was very rich, consisting of button ore and a pinguid shining ore. It answered to his Grace the Duke of Somerset a yearly rent of several hundred pounds. The present lessees are Judicious Thomas Addison, Esq., and Madam Ann Hebar. Being at Egremont I had the curiosity to go to see that rich vein and the stock of ore upon the bank which was like a little mountain. In that great variety of ore I did not only meet with spar as transparent as the clearest crystal, but stones embossed with bastard diamonds near as sparkling as the real!"

A few years ago, when some of the old ore workings near Langhorn were re-opened, several old oak spades were met with, the blade and shaft of each of which were made out of one *straight* piece of wood; that is to say, not only were they

[1] "Essay towards a Natural History of Westmoreland and Cumberland," by Thomas Robinson, 1709.

each formed out of one piece, but there was wanting in them the "lift" of modern spades, being, in that respect, more like the draining tools that are used now. These old spades may have come from the workings which were visited by Robinson, but they more probably belong to an earlier date, although not so old as the time when the monks of the Abbey of Holm Cultram worked ore in the Bigrigg locality; for, along with the old wooden spades, a number of tobacco-pipes were found, and smoking was not introduced into Europe until 1585. In Carew's "Survey of Cornwall," published in 1602, the spades then in use are thus described: "The utter part is of iron, the middle of timber, into which the shaft is slopewise fastened." This spade is clearly an improvement upon those found at Bigrigg for two reasons: first, in having the handle set at an angle instead of being in the same plane as the blade; and secondly, because of its iron edge or shield. At Yeathouse, near Frizington, in some old workings opened out about fifty years ago by Messrs. Tulk and Ley, several old oak spades were found, which were in many respects identical with those from Bigrigg, but there was one important difference in them: they had each a rim of iron on the front edge, which the Bigrigg spades had not. Originally, these latter spades may have been so protected, but as they were in a partially decayed condition when found, the iron edge may have become detached; or it may be that the Yeathouse spade is an improvement upon that found at Bigrigg.

About 1690 iron ore was probably being wrought at Millom, as will appear from the following extract from Nicholson and Burns. "Millum lordship hath several parishes within it. That which lies highest and most southwardly is Millum parish, within which stands the Castle of Millum, the capital messuage and ancient seat of the lords thereof, which is placed at the foot of the river Duddon at the east end of a large park well stored with deer and formerly with great quantities of wood, which Ferdinand Huddleston (having no issue but a daughter), about the year 1690, disposed of, in a great measure, in building of a large ship and in making charcoal for his iron

forge in that park, where he consumed (as is said) much excellent timber to the then value of £4,000 and upwards, and was little or nothing profited thereby."[1]

In 1694 iron ore appears to have been sent by sea from Whitehaven to the Forest of Dean.[2]

In 1745 the Duddon furnace must have been in existence, as it is marked on Speed's map, which was published at that date.

In 1747 Joshua Gee, of Shropshire, took a lease of iron ore in the Frizington demesnes, and soon after commenced to work the ore. In September or October Gee admitted Daniel Stephenson as managing partner. In little over three years from this date Stephenson became bankrupt, and there afterwards arose a dispute between Gee and Stephenson's assignees, as appears from two pamphlets which were issued at the time relating to the dispute. The ore worked was at Yeathouse, and the quantity raised seems to have been between 2,000 and 3,000 tons. Some of it was carted to Parton for shipment, the remainder to Whitehaven, by way of Hensingham. The royalty paid, according to the conflicting accounts in the pamphlets, appears to have been 1*s.* 6*d.* per ton.

In 1750 the Maryport furnace was built, and in 1752 that at Seaton was erected. Fifteen years after this date M. Jars[3] visited Seaton, and found one furnace at work, and another building. The ore used was of a kidney nature, and was obtained partly from mines three or four miles away, and partly from Lancashire.

In 1753-5 iron ore was worked in the parish of Egremont, probably at Bigrigg, by Peter How, William Hicks, Gabriel Griffith, Dr. Brownrigg, and Joseph Bowes. The royalty paid by them was 1*s.* 6*d.* per ton; and during the above-mentioned time they seem to have raised 3,551 tons.

In 1777 iron mines were in existence at Millom.[4]

[1] "History and Antiquities of the counties of Westmoreland and Cumberland," by Nicholson and Burns, 1777.

[2] "Iron-making in the Olden Time," by the Rev. H. G. Nicholls, 1866.

[3] "Voyages Metallurgiques," by M. Jars, 1769.

[4] Nicholson and Burns.

In 1782 iron mining had become so important in West Cumberland, that, in advertising the sale of an estate of land at Ollby (Aldby), near Cleator Moor, it was mentioned that "there was a great prospect of iron ore."[1]

In 1783 an iron-ore royalty of 900 acres at Frizington was offered for sale;[2] and in the same year the Maryport furnace was sold, when it was stated that the ore at the works was from Whitriggs, Crossgates, and Inman Gill (all in Furness), and also from Whitehaven.[3]

In 1794, according to Hutchinson,[4] there was at Crowgarth, near Cleator Moor, "the most singular mine of iron ore supposed to be in Great Britain. It lies," he says, "in the earth at the depth of twelve fathoms, and the thickness of the band of ore, which is hard, solid metal, is between twenty-four and twenty-five feet. It was never known to be much wrought till the years 1784 and 1785, when it was more generally opened; and so great was the demand for it at Carron foundry in Scotland, and others, that in 1790 and 1791 the annual exportation was 20,000 tons and upwards." From this work it also appears that iron ore "(probably hæmatite)" was being wrought in the parish of Arlecdon "(most likely at Yeathouse)," and that the ironstone from the coal measures at Harrington was being exported at the rate of about 2,000 tons annually, the price being about 11*s.* per ton.

In 1796 the furnaces at work in this county and the cast-iron produced by them were as follows:—

	Tons.
Bearpot	240
Duddon	325
	565

[1] *Cumberland Pacquet*, August 27th, 1782.

[2] *Cumberland Pacquet*, January 21st, 1783.

[3] "The Old Maryport Furnace," by John Addison. *Transactions of Cumberland Association for the Advancement of Literature and Science*, Part iv., 1878–9.

[4] "History of the County of Cumberland and some Places adjacent,' by William Hutchinson, F.S.A., 1794.

All this iron would doubtless be produced from local ore, besides which, some of the raw material would probably be exported.

A glimpse of the iron-ore trade in 1816 is obtained from the "Magna Britannica."[1] The authors say: "There is an iron mine also at Bigrigg, in the parish of Egremont, not worked for many years, from which considerable quantities were exported to Hull, etc. The ironworks at Seaton and elsewhere in Cumberland are supplied with pig iron from Wales. Some years ago considerable quantities of a ferruginous sort of limestone were exported from the parish of Arlochden (Arlecdon) to the ironworks at Carron; but the concern has been discontinued." It would appear, therefore, that iron-ore mining in Cumberland had been almost, if not quite, discontinued in 1816.

In 1825 Anthony Hill of the Plymouth Ironworks, South Wales, leased the iron ore in the Bigrigg and Crowgarth Royalties from the Earl of Egremont, and commenced mining operations soon after.

In 1829,[2] according to Parson and White, there were in the parish of Egremont "three extensive ironstone mines belonging to A. Hill, Esq., Mr. Barker, and Fitzsimmons & Co. The iron ore is raised from eight pits twelve or thirteen fathoms deep, and it is found in solid bands, ten yards broad and fifteen feet thick, but at one of the pits the seam is thirty feet thick. The average quantity of ore raised is about one hundred tons per day, and it is all shipped at Whitehaven for the iron foundries of South Wales." From recent inquiries as to the exact position of these mines, it appears that Hill's mines were at Bigrigg, not far from the present Post Office. Fitzsimmons & Co. worked at Langhorn, and Barker in the land which is now known as Dalzell's Gutterby. The deposits worked by these mines were all in the first limestone, which, at the points named, rises out to the glacial drift. From Parson and

[1] "Magna Britannica," by Rev. D. Lysons, and Samuel Lysons, Esq., 1816.

[2] "History, Directory, and Gazetteer of the Counties of Cumberland and Westmoreland," by William Parson and William White, 1829.

White it also appears that, when they wrote, iron ore was being quarried on the Yeathouse estate. They also say that "Frizington Park belongs to Sir F. F. Vane, and has yielded great quantities of iron ore, but the mines have been discontinued."

In 1834 Messrs. Lindow commenced work at Gutterby, and in 1837-38 Mr. James Attwood was raising ore at Frizington Parks, according to Mr. Tulk, from that part of the estate which lies in Winder Valley. Tulk and Ley were the next to work iron ore in West Cumberland, which they did under lease of the Yeathouse estate, dated August 1st, 1838. Mr. Tulk in a letter [1] (from which several items of information in this paragraph were obtained) says: "Previous to my coming to Cumberland (1837), a person of the name of Satterthwaite had worked the Yeathouse Mines for a short time, and, I believe, had obtained 500 or 600 tons."

* * * * *

"This mine must have been worked long antecedent to our" (Tulk and Ley's) "time, for in the course of our working them we found many remains of what had been shafts, and numerous workmen's tools, and some wooden hand-pumps. The shovels we discovered were of oak wood, and merely tipped with an edge of iron." Mr. Thomas Ainsworth was the next raiser of iron ore, but previous to his commencing, Mr. Attwood found and worked ore at Birks, and in small quantities at Aldby.

In 1846 Messrs. Attwood commenced to work at Woodend. Three years later the following companies were raising ore in West Cumberland:—

	No. of Pits.	Output for the year. Tons.
Ainsworth & Co., Cleator	2	30,000
Hill & Co., Bigrigg	4	20,000
John Lindow, Gutterby	3	20,000
Tulk & Ley, Yeathouse	2	15,000
Attwood & Co., Woodend	2	15,000
		100,000

[1] Letter from John A. Tulk, to Geo. Dixon, September 14th, 1863.

TABLE SHOWING THE PRODUCTION OF HÆMATITE IN RECENT YEARS, THE DATE OF OPENING PUBLIC RAILWAYS, AND THE ERECTION OF BLAST FURNACES.

Year.	Ironworks Erected.	Railways Opened.	Total Output of Hæmatite.
			Tons.
1841	Whitehaven	... ...	
1849	... ...	... ...	100,000
1855	... ...	... ...	200,788
1856	... ...	... ...	259,167
1857	Harrington	Whitehaven, Cleator, and Egremont Ry. to Egremont and Frizington ...	323,812
1858	Workington	... ...	331,544
1859	... ...	... ...	400,306
1860	... ...	... ...	466,851
1861	... ...	... ...	472,095
1862	... ...	... ...	533,120
1863	West Cumberland	W. C. & E. Ry., Rowrah Extension ...	690,083
1864	... ...	... ...	784,174
1865	... ...	W. C. & E. Ry., Marron Extension ...	678,831
1866	... ...	... ...	706,505
1867	... ...	... ...	709,037
1868	... ...	... ...	725,248
1869	... ...	... ...	848,974
1870	Maryport, Millom, and Solway	... ...	1,014,143
1871	... ...	... ...	976,874
1872	Mossbay and Lonsdale	... ...	954,505
1873	Parton	... ...	1,021,690
1874	Derwent	... ...	901,667
1875	... ...	... ...	935,360
1876	Lowther	... ...	1,082,812
1877	... ...	... ...	1,081,256
1878	... ...	... ...	1,082,924
1879	Distington	... ...	933,369
1880	... ...	... ...	1,148,246
1881	... ...	... ...	1,615,635
1882	... ...	... ...	1,725,478
1883	... ...	... ...	1,478,062
1884	... ...	... ...	1,358,090
1885	... ...	... ...	1,228,323
1886	... ...	... ...	1,261,655
1887	... ...	... ...	1,479,516
1888	... ...	... ...	1,573,043
1889	... ...	... ...	1,593,890
1890	... ...	... ...	1,431,159

In 1857 the first part of the Whitehaven, Cleator, and Egremont railway, from Whitehaven to Egremont and Frizington, was opened, and from that time the iron-ore trade of West Cumberland has gradually and rapidly increased.

Furness. The iron ore of Furness seems to have been known to the ancient Britons; for, a few years ago, whilst a drift was being made from the foot of a shaft at Stainton, one of the "old men's" workings was discovered, and within it, in front of a breast of ore, two polished stone celts of the usual type were found.[1]

Whether the Romans worked iron ore here is not known, although it is very probable that they did both here and in Cumberland.

The first certain reference to early iron-mining in Furness is in the Chartulary of Furness Abbey.[2] The monks of that place must have wrought iron ore at Orgrave (midway between Dalton and Ireleth) in the early part of the thirteenth century, for it appears that in 1235 there was a dispute between Hamo de Orgrave and the Abbot respecting this ore. Roger de Orgrave was said to have conferred certain mineral rights upon the Abbot, which Hamo, son of the said Roger, disputed.

In 1282, or some subsequent year of the thirteenth century, the convent became possessed of the iron ore under Alinschales (Elliscales), and in the year 1400 they obtained a grant of the iron ore in 400 acres of land in Dalton, Orgrave, and Merton (Martin). It thus appears that some part of the valuable deposits which are now being worked in the localities just mentioned were known at least 600 years ago.

In the reign of Edward II. (1307-1327), William de Lancaster, Lord of Kendal, made a grant of the iron ore at Plumpton to the priory of Conishead. The grant also included land whereon to build a forge, and the dead wood in Blawith for making charcoal.[3]

[1] "Furness, Past and Present," by G. M. Tweddel, 1876.

[2] "History and Antiquities of the Abbey of Furness," by Thomas Alcock Beck, 1844.

[3] Dugdale's "Monasticon," vol. ii., p. 425.

From Holinshed's Chronicles it appears that in 1317, in the reign of Edward II., the Scots, during one of their southerly excursions, "met with no iron worth their notice until they came to Furness, in Lancashire, where they seized all the manufactured iron they could find, and carried it off with the greatest joy, though so heavy of carriage, and preferred it to all other plunder."

Indirect evidence of the working of iron ore is obtained from the certificate of the revenues of Furness Abbey, by the commissioners of Henry VIII. in 1537. They say: "There ys moche wood growing in Furneys Fells in the mounteynes there, as byrk, holey, asshe, ellers, lyng, lytell shorte okes and other underwood, but no timber of any value wherein the abbots of the same late monastry have been accustomed to have a smythey and sometyme two or thre, kept for making of yron to thuse of their monastry, and so now the said commyssyoners have letten unto William Sandes and John Sawrey as moche of the said woodes, that is to saye, of byrkes, ellers, hasells, old rotten trees and other underwoodes as will maynteyne iij smytheys for the whiche they ar content and agreed to paye yerely to the Kinge's highness, as longe as hit shall please his grace they shall occupye the same, xx. li." These smithies were something more than the smithies of to-day, for they actually *made* the iron which they used; and doubtless made it from the ore obtained in Low Furness.

Twenty-eight years after the above date—that is, in 1565—the smithies or bloomeries in the lordships of Hawkshead and Coulton were suppressed, because it was feared by the customary tenants of the said lordships, that the continuance of these smithies would cause a great scarcity of timber, as it was then being largely used for making charcoal, the fuel of the bloomeries. The £20 a year agreed to be paid by Sandes & Sawrey, as mentioned above, was arranged to be afterwards paid proportionally by the customary tenants of the lordships of Hawkshead and Coulton, and of other the lordships, lands, tenements, and hereditaments in the parish of Hawkshead, in

Furness Fells, for ever. This was the origin of the bloomsmithy rent.

According to West[1] an iron forge or bloomery existed at Coniston before the time of the civil wars—that is, prior to 1650. Probably that which existed by the side of Church Beck, near Dixon ground, was the same.

In Robinson's time, 1709, iron ore was worked in the hills about Langdale and Coniston, for he says, page 61,[2] that "Langdale and Cunningston do abound most with iron veins, which supplies with ore and keeps constantly going a furnace at Langdale,[3] where great plenty of good and malleable iron is made, not much inferior to that of Dantzick."

In 1710 the Backbarrow furnace was built by the Machells & Sandys, and in the same year, according to West,[4] "William and John Machell purchased of Walter Strickland, of Sizergh, Esq., 943 timber trees, for £1,700, for the use of" their iron-works in Furness.

From a tract[5] published soon after 1725, we learn something of the importance then attached to the deposits of Lancashire. The writer says: "Cumberland and Lancashire are supposed capable of answering the purposes not only of this nation but even of the Universe."

In 1750 four forges were working in Furness, and they produced the following quantities of bar iron:—

	Tons.
[6] Cunsey	120
Backbarrow	260
Sparkbridge	120
Coniston	80

[1] "Antiquities of Furness," by Thomas West, 1774.

[2] "Natural History of Westmoreland and Cumberland."

[3] This was probably the old furnace of which there are still traces by the side of the River Brathay, between Colwith Force and Little Langdale Farm.

[4] "Antiquities of Furness," by Thomas West, 1774.

[5] "The Interest of Great Britain in supplying herself with Iron.

[6] This forge was by the side of Cunsey Beck, and about three-quarters of a mile from Lake Windermere.

In 1772, according to Pennant,[1] there were extensive mines at Whitriggs. They are thus described by him: "The ore is found in immense beds beneath two strata, one of pinel, or coarse gravel about 15 yards thick; the next is limestone of 20 yards; the stratum of ore is rather uncertain in extent, but is from 10 to 15 yards thick and 40 in extent, and sometimes 200 tons have been taken up in a week. . . . The ore lies in vast heaps about the mines so as to form perfect mountains, is of that species called by mineralogists hæmatite and kidney ore, is red, very greasy, and defiling. . . . The ore is carried on board the ships for 12*s.* per ton, each ton 21 hundred, and the adventurers pay 1*s.* 6*d.* per ton farm for the liberty of raising it. It is entirely smelted with wood charcoal, but is got in such quantities that wood in these parts is sometimes wanting; so that charcoal is sometimes procured from the poor woods of Mull, and others of the Hebrides. The port to these mines is Barrow."

In 1774 West speaks of Whitriggs mines as the "Peru of Furness." He says: "The ore is found there at a depth of 20 to 30 yards; it is raised at 3*s.* 6*d.* and 4*s.* per ton, and pays 1*s.* 6*d.* per ton to the lord of the soil; it is carted and put on vessels for exportation at 3*s.*, and sells from 11*s.* to 12*s.* per ton." He further says, in speaking of Stainton: "The iron mines here have been the richest in Furness."

Between 1785 and 1790 Mr. James Spedding worked mines at Crossgates in Furness. The royalty paid by him was 1*s.* per ton, and the ore was sold for 10*s.* to 12*s.* per ton, F.O.B. Barrow, an inferior black ore, only realising 9*s.* per ton. The output for 1786 and 1787 was 204 tons; for 1788, 3,062 tons; and for 1789, 4,176 tons. The ore was sent to Duddon, Argyle, Seaton, Carron, Monmouth forges, and Clyde Ironworks.

In 1794 Whitriggs was still noted for its iron mines. Hutchinson says:[2] "The roads are deeply stained with ore, and are crowded with carriages bringing it from the mine."

[1] "A Tour in Scotland," by Thomas Pennant, 1790.

[2] "History of the County of Cumberland and some Places adjacent," by William Hutchinson, F.S.A., 1794.

In 1796 the furnaces at work in Furness and the cast iron produced by them were as follows:—

	Tons.
Newlands	700
Backbarrow	769
	1469

All this iron would doubtless be produced from local ore, besides which some of the raw material would probably be exported.

In 1802 iron ore seems to have been sent from Furness to the Forest of Dean.[1]

In 1824 Baines,[2] writing of Furness, says: "The most valuable mineral productions are roofing slate and red hæmatite, a peculiar ore, which is obtained near Ulverston. This is the richest ore in the United Kingdom, yielding the best and most ductile iron, suited for the purpose of the wire-drawers. The ore is also sent to distant parts of England to improve the quality of iron, by mixing it in the furnace with the common ores of iron to increase the ductility of the metal. Crossgates Mines are now (1824) suspended, and the reason assigned is that the mine (ore) is exhausted. The iron mines at Lindal Moor are, however, in full operation. . . . It is difficult, if not impossible, to ascertain the total quantity of iron ore raised in Furness, but the average quantity shipped annually by the firm of Harrison, Ainslie & Co., of Newland, Nibthwaite, Backbarrow, and Sparkbridge, is 10,000 tons. In some years they have raised 15,000 tons, and twice that quantity could be supplied if the demand required it."

The state of affairs in Furness in 1836, so far as relates to iron mines, may be partly learned from the account furnished by Baines.[3] At that date he says: "The digging of iron ore in

[1] "Iron-making in the Olden Time," by H. G. Nicholls, 1866.

[2] "History, Directory, and Gazetteer of the County Palatine of Lancashire," by Edward Baines, 1824.

[3] "History of the County Palatine and Duchy of Lancaster," by Edward Baines, 1836.

Adgarley has lately been resumed. . . . Stainton, the village of stones, like Adgarley, is noted for its iron mines. The principal mineral production of this (Urswick) parish is iron, and the ore was formerly obtained in such abundance, that the mines of Stainton and Adgarley were esteemed the richest in the lordship of Furness. One shaft has been known to yield 140 tons in twenty-four hours, but these beneficial operations were interrupted about twenty years ago by streams of water bursting into the shafts. Recently the works have been resumed in Adgarley by Messrs. Huddleston & Co., lessees under the Earl of Derby. . . . The richest and most productive iron mines in Furness are at Ireleth, or Above Town. The mines of Whitridge, or Whitriggs, described by West as the Peru of Furness, are still worked, and yield valuable ore in large quantities; though the mine called Crossgates became exhausted, and the works were suspended in 1824. The Lindal Moor mines and the Inman Gill mines continue productive; and the Burtonbeck mine has been recently reopened. It is estimated that about 20,000 tons of iron ore are raised annually in the parish of Dalton, and this is said to exceed the production of any former period in this parish. . . . Iron ore has been extensively obtained in the Pennington part of the iron mines upon Lindal Moor, but the works were discontinued in 1830-31, though the other portions are still in operation."

Work was recommenced in Pennington in 1837, and has been carried on continuously since. The output in 1837 was 1,637 tons, in 1884 it was 240,000 tons. From the Buccleugh Royalty adjoining, the output in 1830 was 6,662 tons; in 1884 it was 43,000 tons.

In 1839 the following. companies were working ore in Furness:—[1]

Harrison, Ainslie & Co., Lindal Moor.
Ulverston Mining Co., Lindal Cote.
Mr. T. Fisher, Butts Beck.
Mr. Fisher, Whitriggs.

[1] G. M. Tweddel, op. cit.

In 1846 the first portion of the Furness Railway from Barrow and Piel Pier to Dalton and Kirkby was opened.

At this time the pits working in Furness were :—

	No. of Pits.	Output for the year. Tons.
Harrison, Ainslie, & Co., Lindal Moor	3	55,000
Town & Rawlinson, Crossgates	3	42,000
Ulverston Mining Co., Lindal Cote	4	29,000
Schneider, Davis, & Co., Mouzell	3	25,000
Charles Kennedy, Haulm	1	12,000
George Huddleston, Stainton	2	12,000
George Ashburner, Elliscales	1	7,000
		182,000

Some idea of the extent of the iron-ore trade in Furness during the previous hundred years may be gathered from the following table, which gives the output from the Duke of Buccleuch's royalties alone :—[1]

AVERAGE ANNUAL OUTPUT IN PERIODS OF TEN YEARS.

Years.	Tons.	Years.	Tons.
1750	2,818	1810	9,258
1760	5,277	1820	4,310
1770	6,810	1830	8,080
1780	9,802	1840	13,341
1790	12,491	1850	45,884
1800	11,221		

The table on next page gives the production of hæmatite since 1846, the years in which the various parts of the Furness Railway were opened, and the different blast furnaces erected.

Gloucestershire (Forest of Dean). Iron ore was doubtless wrought here very extensively by the Romans, if not before. Mr. Wyrrall in his MS. (1780) says: "Coins, fibulæ, and other things known to be in use with the Romans have been frequently found in the beds of cinders at certain places. This has occurred particularly at the village of Whitchurch between Ross and Monmouth, where large stacks of cinders have been found, some of them eight or ten feet under the surface."

[1] *Transactions Derbyshire Institute of Mining and Mechanical Engineers—Presidential Address*, 1876.

Year.	Ironworks Erected.	Railways Opened.	Total Output of Hæmatite.
			Tons.
1846	... ...	Furness, Barrow to Dalton and Ireleth	...
1849	... ...	... ...	182,000
1851	... ...	F.R. Dalton to Lindal	...
1852	... ...	F.R. Lindal to Halfway Bridge	...
1854	... ...	F.R. Halfway Bridge to Ulverston	354,685
1855	... ...	... ...	336,829
1856	... ...	... ...	464,853
1857	... ...	F.R. Ulverston and Lancaster	592,390
1858	.. ...	... ...	438,456
1859	Hindpool, Nos. 1, 2	... ...	445,046
1860	" " 3, 4	... ...	520,829
1861	" " 5, 6	... ...	519,180
1862	" " 7	... ...	559,391
1863	" " 8, 9	... ...	658,642
1864	... ...	... ...	691,421
1865	" " 11	... ...	607,439
1866	Carnforth	... ...	685,726
1867	Askam, No. 1	... ...	667,356
1868	... ...	... ...	767,625
1869	" " 2	... ...	784,507
1870	Hindpool, No. 12	... ...	871,938
1871	Askam, No. 3	... ...	931,048
1872	" " 4	... .	909,077
1873	Hindpool, Nos. 13, 14	... ...	975,826
1874	... ...	... ...	914,357
1875	... ...	... ...	834,484
1876	N. Lonsdale, Nos. 1, 2	... ...	908,664
1877	" " 3	... ...	993,012
1878	... ...	... ...	984,781
1879	... ...	... ...	976,822
1880	... ...	... ...	1,266,503
1881	... ...	... ...	1,189,836
1882	... ...	... ...	1,408,693
1883	... ...	... ...	1,372,815
1884	... ...	... ...	1,237,285
1885	... ...	... ...	1,209,971
1886	... ...	... ...	1,216,193
1887	... ...	... ...	1,192,467
1888	... ...	... ...	1,106,013
1889	... ...	... ...	1,021,990
1890	... ...	... ...	968,467

Subsequently to the Roman occupation, the ore of the Forest was probably converted into iron by the Danes and others,—prior to the Noman Conquest,—whence the name "Danes' Cinders" given to the large heaps of iron slag which at one time were to be found all over the forest.

Coming to more recent times,—*i.e.*, somewhat prior to 1154,—we find that the first charter granted to the Abbey of Flaxley by Henry II., whilst Duke of Normandy, specifies an ironwork at Edlaud, now Elton, near Westbury, on the eastern side of the forest,[1] so that presumably iron ore was being mined in the forest then. His second charter, when king, is more explicit, and describes "an iron-forge, free and quit, with as free liberty to work as any of his forges in demesne."

In 1188 Geraldus Cambrensis, describing his tour through Wales, speaks of "the noble Forest of Dean, by which Gloucester was amply supplied with iron."

In 1216, at the commencement of his reign, Henry III. commanded John de Monmouth to cause Richard de Eston to have his forge working in the Forest of Dean, at Staunton, according to the charter of Henry II.[2] above mentioned. About this time the ironworks appear to have grown undesirably numerous, so as to cause great waste of timber in the Forest; for in the same year "the Constable of St. Briavell is ordered to remove, without delay, all forges from the Forest of Dean, except the King's demesne forges, which belong to the Castle of St. Briavell, and ought to be sustained with trunks of old trees wherever they are found in the demesnes in the Forest; excepting two forges belonging to Ralph Avenell, concerning which he has the charter of King John and excepting four 'Blissahiis' Will. de Dene, and Robert de Alba Mara, and Will. de Albenhale, and Thomas de Blakencia, and excepting the forges of our servants of St. Briavells which ought to be sustained with dry and dead wood."[3]

In 1220 (4 Henry III.) "John de Monmouth is com-

[1] Rudder's "Appendix," pp. 25, 26.
[2] "Rotuli Litterarum Clausarum."
[3] *Ibid.*

manded not to permit any forge to work, either with green or dry wood, in the Forest of Dean, besides the demesne forges."[1]

In the same year John de Monmouth is commanded to permit the Abbot and monks of Flaxley to have their forge working in the Forest of Dean, according to the charter of Richard I., in the same manner as they had it in the time of King John, notwithstanding that all forges are prohibited in the Forest, except the demesne forges.[2]

In the same year John de Monmouth is commanded to permit Walter de Lacy to have his forge (*fabrica*) in the Forest of Dean, as he was accustomed to have it in the time of Henry II. and John.

John de Monmouth also received the king's directions as follows: "William Fitzwarren has shown the King, that whereas Walter de Lacy gave him a forge, which the said Walter and his Ancestors have been accustomed to have temp. Henry II., Richard I., and John, and which was prohibited in our general prohibition—We command you to allow the said William to have the said forge (*fabrica*) moveable in the Forest, but that the forge which the said Walter erected without our order shall remain quiet (*remanenta otiosa*)."

In 1221 John de Monmouth is ordered to allow Philip de Bantun and fifteen others to have their *forgias itenerantes ad mortuum et siccum*, as they were accustomed to have them temp. Richard I. and John.[3] A similar privilege was granted the same year to Matilda de Cantilupe and Henry Earl of Warwick, as well as to Walter de Aure and Richard de Estun;[4] so likewise in 1223 (7 Henry III.) the monks of Flaxley were directed to have *forgiam Suam* as in the time of King John.

For the year ending November 16th, 1256, the issue in money to the Crown "from the great and little mines" in the Forest was £23 1*s*. 4*d*.

[1] "Rotuli Litterarum Clausarum."
[2] *Ibid.*
[3] *Ibid.*
[4] *Ibid.*

In 1268, by an Inquisition of the 52 Henry III. to ascertain what privileges the Abbot and Convent of Tynterne were accustomed to have in the Forest, the jurors returned that "the said Abbot and Convent, by charters of the King's predecessors, are accustomed to have mines in the Forest for their own forge freely and have never given anything for the said mines,"[1] 4 Edward I. 1276.[2] Ralph de Sandivico, custos of the Castle and Manor of St. Briavell, in his return of moneys received on behalf of the Crown from the iron mines and forges during that year, states as paid, £23 16*s.* 9½*d.* from the great and little mines of iron and coal, £11 6*s.* 0*d.* rent of forges in the Forest, £5 15*s.* 0*d.* by sale of cinders (*Cineribus*). This last item seems to show, that even then it was customary to use the old cinders left from the still more ancient workings.

In 1282 a "regard" of the Forest[3] taken (10 Edward I.) *de forgeis in Foresta*, records, that there were 60 forges at work in the district of the Forest at this time, 19 on the east side, 6 on the south, 23 on the west, and 12 on the north.

The same "regard" specifies *iron mines* in the Bailiwicks of Abenhale, Bikenore, Blackeneye, Magna Dene, Birs, Staunton, and Lacu, the mines, like the forges, being mostly on the Wye side of the Forest.

Thirty-five years later than the former return there were only 43 forges at work in the Forest.[4]

In or about 1300, the "Book of Dennis, or the Miners' Lawes and Privileges," was written, so that it is certain the iron-ore industry had attained to great importance at that time.

In 1341 (14 Edward III), on the completion of Newland church, the Bishop of Llandaff obtained a grant of the tenth part of the ore raised in the neighbourhood; which, together with the forest forges, yielded a rental of £34 that year.[5]

Other places, such as Caerleon, Newport, Barkley, Mon-

[1] "Exchequer Records," No. 29. Chapter House.
[2] Inquisition 15 Edward III., "Exchequer" Records, No. 75.
[3] "Exchequer Records," Ch. v., f. 18, No. 18, Col. 1.
[4] "Chapter House Records."
[5] "Exchequer Records."

mouth, and Trellech, obtained their ore from this neighbourhood.[1]

In 1376[2] the Governor of Berwick-upon-Tweed was obliged to send for miners from the Forest of Dean, and the more southern parts, to assist him in retaking the town from the Scots.

In 1485 Henry VII (February 1st) granted the mines beneath the wood, Vocat le Gawle, to John Motten for life.

In 1538 Leland, in his Itinerary, speaking of the Forest, says: "The ground is fruitful of iron mines, and divers forges be there to make iron."

In 1566 (June 30th) William Humphrey, upon information derived from some German miners, addressed a letter to Sir William Cecill, about the plenty of good iron contained in the Forest of Dean.[3]

In 1611 (May 16th,)[4] a grant was made to Henry Lord Herbert, Henry Poole, and George Huntly, of coppices in the Forest of Dean, with leave to cut them down for charcoal for making iron.

In 1612 James I. granted to the Earl of Pembroke a lease of the Forest of Dean, together with the iron ore, cinders, coal, and wood, for twenty-one years, at the rent of £2,433 6*s.* 8*d.*

In 1615 (May 31st)[5] the office of clerks or overseers of the ironworks in the Forest of Dean was granted to Sir Basil Brooke and Robert Caldecott for fifteen years.

In 1621[6] all ironworks, with furniture belonging thereto, in the Forest of Dean were granted to Phil Harris and others for seven years.

In 1625 Charles I. granted to Sir Edward Villiers, Knt., and to his heirs, a part of the waste soil of the Forest, called Malyscott, together with all woods growing thereon and all mines, etc.

Fourteen years afterwards the King granted to Sir John

[1] "Book of Mine Law."
[2] Holinshed's "Chronicles."
[3] State Papers.
[4] State Papers.
[5] *Ibid.*
[6] *Ibid.*

Winter, Richard Brayne, Tristam Flowers, and others, 18,000 acres, and all the mines of iron, etc.

In 1629 (March 31st),[1] Charles I. granted the ironworks in the Forest of Dean to the Lord Steward for twenty-one years, with 10,000 cords of wood to be yearly taken out of the Forest.

In 1635, we learn, from a survey of the Forest of Dean ironworks, that there were furnaces at Cannop, Park, Sowdley, and Lydbrook, and forges at Parkend, Whitecroft, Bradley, and Lydbrook.

In 1662[2] (12th April), an elaborate return addressed to the Barons of the Exchequer, suggested that a check should be put to the practice of exporting from the Forest both ore and cinders, lest the king's own works should need them.

In 1677 Andrew Yarranton said:[3] "In the Forest of Dean and thereabouts, the iron is made at this day of cinders (with ore), being the rough and offal thrown by in the Romans' time; . . . the greatest part of this iron is sent up Severne to the forges into Worcester, Shropshire, Staffordshire, Warwickshire, and Cheshire, and there it's made into bar iron, and because of its kind and gentle nature to work, it is now used at Sturbridge, Dudley, Wolverhampton, Sedgley, Walsall, and Birmingham, and there bent, wrought, and manufactured into all small commodities."

In 1678, Henry Powle,[4] speaking of the forest, says: "Iron ore, which is the principal manufacture here, and by which most of the inhabitants subsist, is found in great abundance in most parts of the forest."

In 1680 (April 27th), the 4th order of the Mine Law Court fixed the price at which 12 Winchester bushels of ore should be sold at the following places: St. Wonnarth's furnace 10*s*., Whitechurch 7*s*., Surton 9*s*., Bishopswood 9*s*., Longhope 9*s*., Flaxley 8*s*., Gunnsmills (if rebuilt) 7*s*., Blakeney 6*s*., Lydney 6*s*.

[1] State Papers.

[2] British Museum, *Harleian MS.* 6839, fol. 332.

[3] "Improvement of England by Sea and Land."

[4] *Philosophical Transactions*, vol. xii., p. 931.

Speaking of this time, Dr. Parsons says: "The ore and cinder, wherewith they make their iron, are dug in most parts of the Forest, one in the bowells, and the other towards the surface of the Earth."

About 1720 or 1730, according to a paper examined by Mr. Mushet, there were ten blast furnaces in the Forest.

In 1779 Rudder writes:[1] "The Forest is full of iron ore."

In 1788 Mr. Hopkinson said before a Parliamentary Commission: "There is no regular iron-mine work now carried on in the Forest; the mines," he said, "have been worked out many years." But in 1795 the manufacture of iron was resumed in the Forest with pit-coal cokes at Cinderford,—this date being marked on a stone in No. 1 furnace.

In 1799 Parkend furnace (suppressed in 1674) was resumed, and one or more furnaces have been in operation there, more or less, under different proprietors ever since.

The Rev. T. Rudge, writing in 1802, says: "Lancashire ore furnishes the principal supply; the mines found in the Forest being either too scanty to answer the expense of raising it, or, when raised, too difficult of fusion."

The yield of ore by the Forest mines in 1828 was 9,800 tons; in 1836 it was 20,408 tons; and in 1839 72,800 tons.

In 1837 blast furnaces were erected at Sowdley. Iron-works had existed there since 1565, and have continued to work since more or less interruptedly.[2]

Since 1854 the course of the iron trade in the Forest will perhaps be best indicated by the following table of production:—

Year.	Tons.	Year.	Tons.
1854	85,506	1861	100,419
1855	92,608	1862	158,908
1856	109,268	1863	121,397
1857	127,554	1864	130,482
1858	107,652	1865	142,807
1859	106,292	1866	156,079
1860	90,466	1867	156,069

[1] "New History of Gloucestershire." [2] State Papers.

Year.	Tons.	Year.	Tons.
1868	160,722	1880	83,198
1869	134,595	1881	90,617
1870	138,254	1882	80,752
1871	170,611	1883	70,942
1872	162,888	1884	63,043
1873	163,660	1885	45,125
1874	110,203	1886	61,616
1875	92,825	1887	68,729
1876	98,133	1888	70,201
1877	80,555	1889	52,156
1878	69,034	1890	65,611
1879	52,061		

Sussex and Kent. Iron ore is not raised in these counties now, and has not been for years, but in the old charcoal days they occupied a foremost place in British iron manufacture. The general introduction of coke elsewhere and the consequent scarcity of charcoal in the seventeenth and early part of the eighteenth century, however, placed them at a great disadvantage in the struggle for existence, so that the number of furnaces in these counties became greatly reduced, and ultimately iron-making ceased in them altogether. Near the base of the Wadhurst clay, in the Weald, nodules and thin tabular masses of clay-ironstone occur, which have been worked very extensively in former times, by the Romans amongst others. It is known that the Romans extracted ore at Waresfield, Framfield, Sidlescombe, Westfield, and Chiddingly in Sussex, and probably at Cowden in Kent. At Old Land Farm near Maresfield, Roman pottery, coins, etc., were discovered amongst iron slags.[1] It is possible, however, that these beds were worked even earlier than the Roman period, for flint, flakes, and rough unturned pottery were found in 1862 by Mr. W. Boyd Dawkins[2] on the surface of a slag heap, north of Bathurst wood, near Battle.

A long time then intervenes, of which nothing is known

[1] Lower, "Contributions to Literature," p. 98.

[2] *Transactions International Congress of Prehistoric Archaeology, 3rd Session*, 1868.

regarding the ironworks. There is no mention of them even in Domesday Book, although furnaces are mentioned elsewhere; but in 1266 a grant was made to the town of Lewes by Henry III., which empowered them to levy toll for the repair of the Town Hall. "Every cart laden with iron from the neighbouring weald, for sale, paid one penny toll, and every horse-load of iron half that sum."[1]

In 1543 Holinshed[2] writes: "This year the first cast pieces of iron (ordnance), that ever were made in England, were made at Buxteed in Sussex."

In 1574 there were, according to a return of all the owners of ironworks, in Kent, Surrey, and Sussex, 38 forges and 32 furnaces in Sussex, but there were "dyvers fordgs and furnaces"[3] in other places.

In 1607 John Morden[4] writes: "I have heard there are, or lately were, in Sussex, 140 hammers and furnaces for iron."

In 1640 (March 31st) pardon was granted to William Yalden, gentleman, of all offences by him committed before May 17th, 1636, in destroying divers wood for the smelting of iron in the counties of Surrey, Sussex, and Hants.

In 1650 there appear to have been 27 furnaces and 42 forges in Sussex, many of which were discontinued before 1664.[5]

In 1740 there were four furnaces in Kent and 10 in Sussex, and in 1788 only 2 in the latter county and none in Kent.[6]

In 1782 Hasted,[7] in noticing the Lamberhurst furnace, says: "The iron ore is found in great abundance in most parts of these woods, but different in colour, weight, and goodness. That which is unfit for common use on account of its being short and brittle, when melted, is mingled in due quantity with cinder, being the refuse of the ore, after the metal has been

[1] Lower, "Contributions to Literature."
[2] "Chronicles."
[3] State Papers.
[4] Surveyor's Dialogue.
[5] "Sussex Archæological Collection," vol. xviii., p. 15.
[6] "Encyclopædia Britannica," 8th ed., article "Iron."
[7] "History of Kent," vol. ii., p. 382.

extracted from it, which gives it that temper of toughness which makes it fit for use."

In 1796 only one furnace remained in Sussex. That was at Asburnham. It continued working until 1828, and was then abandoned, being the last of the Weald furnaces.

Staffordshire, Warwickshire, Worcestershire, and Salop. Little is known of the iron trade here during Roman, Saxon, and Norman times. Andrew Yarranton[1] says, he "found out a vast quantity of Roman cinders near the wall of the city of Worcester; and within one hundred yards of such walls there was dug up one of the hearths of Roman foot-blasts, it being then firm and in order, and was seven foot deep in the earth; and by the side of the work there was found out a pot of Roman Coin—to the quantity of a peck—some of which was presented to Sir Dugdale, and part thereof is in the King's closet; by all which circumstances, it clearly appears that the Romans made iron in England; and as far up the River Severn as the city of Worcester, where, as yet, there are vast quantities remaining."

In 1538[2] Leland says that "at Walleshall there is also yren owre"; and in the Clee hills, "There be some bloshops to make yren upon the ripes or banks of Millbroke coming out of Caderton Clee." Stow, in his notes to this writer, says: "They get yren out of Staffordshire and Warwickshire."

The ore at Walleshall is referred to by Holinshed[3] in 1586. He also speaks of ore in Shropshire.

In 1607 Camden,[4] writing of south Staffordshire, says: "It has much pit coal and mines of iron."

In 1665, Dud Dudley,[5] referring to Staffordshire, says: "If the coals and ironstone so abounding were made right use of, we need not want iron as we do, for very many measures of ironstone are placed together under the great ten yards thickness of coal, and upon another thickness of coal, two yards

[1] "England's Improvement by Sea and Land." First part published 1677, second 1688.

[2] "The Itinerary."

[3] "Chronicles."

[4] "Britannia."

[5] "Metallum Martis."

thick, not yet mentioned, called the bottom coal or heathen coal."

In 1670 Sir John Pettus[1] says: "Iron oar is plentiful in Shropshire and Staffordshire."

In 1686 Dr. Plot,[2] describing the iron ores of Staffordshire, speaks of their occurrence at Dudley, Walsall, Rushall, Chestinhay, Redstreet, Apedale, Wednesbury, and Darlaston. The measures then wrought at Dudley were the Black row grains, Dun row grains, White row grains, Ryderstone, Cloudstone, Bottomstone, and Cannoc or Cannotstone. At Walsall and Rushall the stones worked were named Blackbothum, Graybothum, Chatterpye, Grey measure, Mush, and White measure.

In 1735 Abraham Darby succeeded in making iron at Coalbrookdale ironworks with coke. In 1756 he commenced making iron in his works at Horsehay.

In 1747 Rev. Mr. Mason[3] speaks of Mr. Ford, of Coalbrookdale, being able to "make iron brittle or tough as he pleases from iron ore and coal both got in the same dale."

Gough, writing in 1806, says: "Twelve miles east of Wellington is an extensive parish, including fourteen villages; the inhabitants are chiefly employed in getting coal, lime, and ironstone. There are two furnaces worked by a steam-engine, one of the largest in England. In the ironstone about Ketley are impressions of plants and shells."

The production of iron in these counties at different periods between 1740 and 1830 is given in the following table:—

	Staffordshire. Tons.	Shropshire. Tons.
1740	1,000	
1788	2,400	24,900
1796	17,910	32,969
1806	50,002	54,966
1830	211,604	73,418

[1] "Fodinæ Regales."

[2] "Natural History of Staffordshire."

[3] *Philosophical Transactions*, No. 482, p. 382.

In 1836[1] Thomas Smith, writing on the coal and ironstone measures of South Staffordshire, says: "They occupy an area nearly twenty-two miles in length, from Stourbridge in Worcestershire, to the neighbourhood of Rugeley, and about six miles in its greatest breadth; . . . but this extended space is divisible into two distinct portions, of which the southern is circumscribed by a line drawn from Wolverhampton through Walsall, West Bromwich, Oldbury, Halesowen, Stourbridge, King Swinford, and Sedgeley, to the point of its commencement at Wolverhampton." The measures then wrought were the Black Gubbin, Poor Robin, White Ironstone, Ball Ironstone, Lower Gubbin Ironstone, and Blue Flats.

In North Staffordshire the measures wrought at this time were the Cannel Mine, the Blockstone, the Sheathstone, the Chalky Mine, the Little Mine, and Brown Mine. In East Shropshire they were working the Penny Ironstone, Black Ironstone, Brick Measure, Ballstone, Yellow Ironstone, Blue Flats, and White Flats. There is nothing said about ironstone being wrought in Warwickshire then.

PRODUCTION OF IRON ORE SINCE 1859.

	Staffordshire. Tons.	Warwickshire. Tons.	Salop. Tons.
1859	1,583,000	30,500	197,589
1860	1,518,929	19,500	165,500
1861	1,226,695	15,250	223,400
1862	1,346,000	14,750	225,400
1863	1,531,809	12,500	247,200
1864	1,531,250	15,750	454,000
1865	1,484,991	16,500	273,810
1866	1,211,243	18,750	285,907
1867	1,319,509	15,500	250,000
1868	1,127,459	14,795	278,541
1869	1,637,749	15,000	318,483
1870	1,360,134	17,500	337,627
1871	2,218,745	34,075	415,972
1872	—	43,375	408,425
1873	—	43,837	430,725

[1] 'Miners' Guide."

		Staffordshire. Tons.		Warwickshire. Tons.		Salop. Tons.
1874	...	—	...	92,214	...	303,959
1875	...	1,654,474	...	97,456	...	240,568
1876	...	—	...	92,838	...	239,183
1877	...	1,852,938	...	79,965	...	270,733
1878	...	1,664,394	...	57,222	...	321,328
1879	...	1,522,773	...	16,214	...	300,391
1880	...	1,713,088	...	36,972	...	226,721
1881	...	1,738,594	...	31,513	...	190,000
1882	...	2,022,529	...	36,038	...	242,500
1883	...	1,797,444	...	31,404	...	235,900
1884	...	1,873,745	...	16,801	...	198,700
1885	...	1,829,571	...	10,981	...	177,620
1886	...	1,591,055	...	1,344	...	137,900
1887	...	938,018	...	1,838	...	100,600
1888	...	1,689,768	...	4,230	...	131,100
1889	...	1,262,678	...	1,723	...	44,630
1890	...	1,224,510	...	2,155	...	47,059

Derbyshire and Yorkshire. The earliest working here seems hidden in obscurity, but judging from the numerous old slag-heaps scattered about, the ore of the coal measures, appears to have been used somewhat largely in the old bloomeries. Farey, writing in 1811,[1] gives the following list of twenty-three places, where he had seen slag and remains of old bloomeries and charcoal furnaces:

Alderwasley, in Wirksworth.
Barlow, E.
Butterley, in Pentrich.
Carr, in Palterton.
Cinderhill, in Horsley.
Coburn, in South Winfield.
Denby.
Ford, in Eckington.
Foremarke, north-west of the Park.
Foxton-dam, in Renishaw.
Hartshorn.
Heanor, north-west.
Jow-hole, near Beard, in Glossop.

[1] "General View of the Agriculture and Minerals of Derbyshire."

Kirkby, south-west Notts.
Melborne (woodhouses).
Moscar-house, quarter mile south-east of Athersage.
New-Mill, in Aston, Yorkshire.
Parkhill Farm, „ „
Quarnford, near Winch Chapel, Cheshire.
Stockby, west of Palterton.
Todhole Furnace, in Shirland.
Walley, in Bolsover.
Wingerworth Furnace.

There are also accumulations of old iron slag in Bilsdale, Bransdale, Rosedale, Fryupdale, etc., in Yorkshire, evidently from smelting the ore of the Lower Oolite.

An Inspeximus[1] dated at York, February 26th, 1328, 2° Edward III., recites a grant, made August 16th, 1209, by Robert de Stuteville, of a meadow in Rosedale, to the nuns of that place, *near to his forge.*

In 1607 Camden,[2] speaks of the Peake as rich in lead, iron, and coal.

Borlase,[3] in 1758, refers to the iron ore of Derbyshire.

In 1780 the Bowling Ironworks were projected, and those at Low-Moor in 1790.

John Mawe,[4] in 1802, says the "Argillaceous iron ore is in the most general use in the ironworks. It is sometimes mixed with a proportion of Lancashire ore."

Below is a statement showing the production of iron in each of these counties, between 1740 and 1830.

	Yorkshire (West Riding). Tons.	Derbyshire. Tons.
1740	1,400	550
1796	10,398	9,656
1806	27,646	10,329
1823	27,311	14,038
1830	28,926	17,999

[1] Dugdale's "Monasticon," vol. i., p. 507.
[2] "Britannia."
[3] "Natural History of Cornwall."
[4] "Mineralogy of Derbyshire."

In 1806 there were in Derbyshire eighteen furnaces built and twelve in blast, as shown in the following table:—

Year. Built in	Place.	Built.	In Blast.	Production.
				Tons.
...	Morley Park	1	1	700
...	Chesterfield (Guffin) ...	3	2	1700
...	„ (Stone Gravel)	2	1	700
1780	Wingerworth...	2	1	819
1786	Staveley	1	1	596
1788	Dale Abbey	1	—	—
1792	Butterley	2	2	1766
1792	Renishaw	2	1	975
...	Alfreton	1	1	1450
...	Hasland	1	1	723
1799	Duckmanton	2	1	900
...	Total	18	12	10,329

At this time there were fourteen furnaces in Yorkshire.

In 1811 the Cleveland Main Band appears to have been discovered, but was very little worked until 1850. Since that time the output has gone on increasing, as shown by the table below, until it is now one of the most important sources of iron in the British Isles.

Middlesbrough and Guisborough Railway, opened 25th February, 1854; Rosedale Branch, April 1861.

PRODUCTION OF IRON ORE SINCE 1855.

		Yorkshire.				Derbyshire.
		Cleveland. Tons.		West Riding. Tons.		Tons.
1855	...	865,300	...	255,000	...	409,500
1856	...	1,148,488	...	242,100	...	392,400
1857	...	1,414,155	...	207,500	...	350,000
1858	...	1,367,395	...	189,750	...	328,950
1859	...	1,520,342	...	175,000	...	325,500
1860	...	1,471,319	...	255,700	...	387,500
1861	...	1,242,514	...	235,500	...	396,520
1862	...	1,689,966	...	350,500	...	345,450
1863	...	2,078,806	...	475,000	...	350,500
1864	...	2,401,890	...	555,000	...	325,600
1865	...	2,762,359	...	575,000	...	350,000

	Yorkshire. Cleveland. Tons.	Yorkshire. West Riding. Tons.	Derbyshire. Tons.
1866	2,809,061	357,000	329,500
1867	2,739,039	579,000	350,000
1868	2,785,307	785,028	368,440
1869	3,094,678	230,905	352,072
1870	4,072,888	307,717	384,865
1871	4,581,901	407,997	492,973
1872	4,974,950	466,305	307,183
1873	5,617,014	407,388	365,127
1874	5,614,322	370,960	239,292
1875	6,121,794	353,582	218,132
1876	6,562,000	381,463	199.908
1877	6,284,545	402,746	206,247
1878	5,605,639	370,405	175,260
1879	4,750,000	321,789	146,341
1880	6,486,654	286,698	150,248
1881	6,538,471	320,981	59,207
1882	6,326,314	175,681	15,011
1883	6,756,055	170,832	16,838
1884	6,052,608	167,812	19,296
1885	5,932,244	126,596	18,406
1886	5,370,279	92,285	11,920
1887	4,980,421	81,868	5,799
1888	5,395,942	67,148	11,823
1889	5,728,314	71,196	18,689
1890	5,617,573	77,433	23,732

Devon, Cornwall, and Somersetshire. Iron-ore mining does not appear to have reached much importance at any time in these counties, although they doubtless contain a large quantity of iron ore.

In the Ebbw Vale Museum is a Roman coin of the reign of Domitian, said to have been found in the old workings at Kennesome Hill, West Somerset.

Iron ore appears to have been worked in the Mendips in 1538, for it is referred to by Leland in his "Itinerary," and Holinshed in 1586 also speaks of it.

In 1670 Sir John Pettus [1] says, "Iron oar is plentiful in Cornwall."

[1] "Fodinæ Regales."

In 1758 Borlase[1] writes: "There are many" (iron lodes) "in Cornwall,—but not that I have heard, or can learn, worked as yet to effect, although in some of them the ore is very rich and near the surface." In 1778[2] these ores still remained unworked.

Between 1796 and 1802[3] 9,293 tons of iron ore were shipped to Llanelly, in South Wales, from a lode near Combe Martin, North Devon.

In 1806 we learn, from Gough's additions to Camden's "Britannia," that "Iron ore is found in Cornwall, but the working it does not answer,—nor have any of the mines been worked." The same writer says that "Iron is profusely scattered through every part of Devonshire; but though some ores of peculiar value have been shown, there is no evidence of their being in strata so extensive as to render the working them advantageous."

In 1839, according to De la Beche,[4] iron ore was being wrought at Lostwithiel, Nantallan Downs, near Bodmin, St. Stephen's, Lanivet, Ladock in Cornwall, and at Brixham and Shaugh Prior in Devon. The Ebbw Vale Company began work at Brendon Hills in 1852, but old surface workings were in existence then.

The production of iron ore in these counties since 1855 has been as follows:—

	Cornwall. Tons.	Devonshire. Tons.	Somersetshire. Tons.
1855	24,057	1,500	4,940
1856	22,650	4,100	14,620
1857	19,359	2,000	25,342
1858	55,150	4,754	26,041
1859	35,213	3,598	29,083
1860	23,953	3,836	24,101
1861	26,262	5,399	32,763

[1] "Natural History of Cornwall."

[2] Price's "Mineralogia Cornubiensis."

[3] "Magna Britannica," *Devon*, p. 289.

[4] "Report on the Geology of Cornwall, Devon, and West Somerset."

		Cornwall.		Devonshire.		Somersetshire
		Tons.		Tons.		Tons.
1862	...	24,626	...	3,550	...	31,443
1863	...	18,975	...	7,014	...	34,709
1864	...	34,210	...	11,068	...	54,925
1865	...	36,112	...	37,814	...	37,984
1866	...	18,683	...	40,671	...	35,323
1867	...	6,426	...	10,212	...	36,875
1868	...	8,310	...	11,178	...	32,450
1869	...	4,619	...	7,104	...	27,230
1870	...	11,214	...	10,103	...	19,739
1871	...	21,947	...	14,124	...	32,883
1872	...	48,199	...	29,361	...	30,913
1873	...	31,455	...	31,455	...	46,532
1874	...	45,055	...	21,313	...	41,342
1875	...	11,403	...	10,594	...	45,166
1876	...	18,390	...	9,936	...	44,299
1877	...	4,963	...	6,434	...	51,927
1878	...	1,308	...	4,493	...	43,115
1879	...	400	...	592	...	14,100
1880	...	7,460	...	12,652	...	29,318
1881	...	5,749	...	11,198	...	30,371
1882	...	670	...	11,481	...	36,067
1883	...	950	...	5,240	...	4,421
1884	...	—	...	1,303	...	3,582
1885	...	75	...	1,928	...	2,099
1886	...	—	...	1,010	...	4,031
1887	...	—	...	2,621	...	1,484
1888	...	—	...	2,085	...	1,388
1889	...	—	...	3,280	...	1,400
1890	...	—	...	4,155	...	636

Durham and Northumberland. There can be very little doubt that the Romans worked iron ore in these counties.

The Rev. I. C. Bruce[1] says that "iron has been procured" (by the Romans) "in large quantities. In the neighbourhood of Habitancum, masses of iron slag have been found, and in the neighbourhood of Lanchester the process seems to have been carried on very extensively. On the division of the common, two large heaps were removed, the one containing about 400 cartloads of dross, the other 600." Similar old heaps

[1] "The Roman Wall," 1853.

of slag occur at Chester-le-Street, and in the valleys of the Reed and Tyne.

In 1245, it appears from a catalogue of the possessions of Gilbert d'Umfraville, lord of Redesdale, that bloomeries existed somewhere in Redesdale, for there are mentioned "*forgiæ quæ reddunt ferrum quod reddit per annum iiij.l. ij.s.*"

Iron ore was worked in Weardale in 1586, according to Holinshed.[1]

In the reign of William III. a colony of German iron-workers established themselves at Shotley Bridge.

Wallis, in 1769,[2] mentions an ironwork which existed some years previously at Lee Hall, near Bellingham.

In 1800 the Tyne Iron Company erected two furnaces at Lemington to smelt the ironstone from the coal measures at Walbottle, Elswick, etc.

In 1806 Gough [3] says: "There is both iron and lead ore in Weredale."

Between 1830 and 1840 ironworks were erected at Birtley, Ridsdale, Hareshaw, Wylam, Shotley Bridge, and Consett, for smelting local ironstone from the coal and limestone measures.

In 1842 a furnace was erected at Stanhope, and three years later five others at Tow Law for smelting the "rider" ore, accompanying the lead veins in Weardale.

In recent years, the extent to which the ores of these counties have been wrought will be gathered from the following table of output:—

Year.	Clayband. Tons.	Spathic Ore and Limonite. Tons.
1870	125,000	100,332
1871	196,848	88,449
1872	—	97,953
1873	55,981	99,393
1874	54,660	85,491
1875	45,317	34,828
1876	14,961	24,202
1877	31,858	51,344

[1] "Chronicles."
[2] "History of Northumberland."
[3] Camden's "Britannia."

Year.	Clayband. Tons.	Spathic Ore and Limonite. Tons.
1878	19,204	35,619
1879	8,508	16,679
1880	24,439	41,357
1881	—	70,701
1882	—	83,726
1883	—	50,248
1884	—	49,091
1885	—	39,777
1886	—	1,759
1887	—	2,506
1888	—	47,193
1889	—	3,991
1890	—	11,488

Northamptonshire, Lincolnshire, Leicestershire, Rutlandshire, Oxfordshire, and Wiltshire. That the Romans worked iron ore in some of these counties is evident from the numerous accumulations of slag, associated with Roman coins and pottery, occurring at such places as King's Cliff, Oundle, Laxton, Rockingham, Kettering, and Irchester in Northamptonshire.

"Iron-smelting[1] seems to have dwindled during the Saxon and Norman ages, although Domesday Book mentions Ferraria, at Gretton and Corby, in Edward the Confessor's reign, and it is recorded that royal furnaces were in work at Geddington from the time of Henry II. to Henry III." The practice of iron-making, soon after this, appears to have died out, and not to have been revived until about forty years ago. S. H. Blackwell, of Dudley, says: "An investigation at the close of the exhibition (1851) was rewarded by the discovery at Higham Ferrers of a bed of ore many feet in thickness. This led to further examination, and to the discovery of the Northampton deposits."

In 1855 attention was first directed to the iron ores of Wiltshire, and in 1858 the iron ore in the lower lias at Scunthorpe, in Lincolnshire, was first worked. About the same

[1] Address by John Evans at Northampton, 1878.

time, or a little later, the ore of the Middle Lias of Oxfordshire began to be worked.

The working of the ore in the Lower Oolite, near Lincoln City, was commenced in 1873.

In 1882 the deposits at Holwell, Eastwell, Waltham, and Wartnaby in Leicestershire were opened out.

The production of ore in these counties since 1855 has been as below:—

Year.	Northamptonshire.	Lincolnshire.	Oxfordshire.	Wiltshire.	Leicestershire.

Glamorganshire, Brecknockshire, and Monmouthshire. The Romans, says Williams in his "History of Monmouthshire," introduced iron foundries into Siluria at Monmouth, Hadnock, Keven, Pwlldu, and other parts of the county.

Four miles north-east of Bolston Gaer, near Miskin, a coin of Antoninus Pius and a piece of fine earthenware were found, in 1762, under a large bed of cinders.

Dr. Watson, writing on the hæmatite deposits of Glamorganshire in 1859,[1] says: "Some coarse pottery of undoubted Roman manufacture was found a few years since buried in a small pit made in the bottom of an ancient stall-working at Ty-Ischaf. The pottery, which consisted of small amphoræ, was accompanied by some bones."

In 1538 Leland, in his "Itinerary," says: "There are two parkes by the South of Llantrissant, now onpaled and without deere. There is yrun made in one of these parkes."

Ironworks appear to have been erected at Pontypool soon after 1565, and a regular account of the sales of iron (from those works) commences in 1588.[2]

In 1670 Sir John Pettus[3] writes thus: "The other great works was of iron at Whitbrook and Tintorne in Monmouthshire, for the working of iron wier, and this work, and other Ironworks which support them, did also employ at least four thousand men dailie, and so have done for many years."

In 1740 the production of iron in these counties and Caermarthenshire was only 2,000 tons. In 1788 it was 12,500 tons, in 1796 it had risen to 34,101 tons, and in 1830 to 127,340 tons.

In, or about, 1750, according to a MS. in possession of Mr. Octavius Morgan, "On the mode and cost of making iron in South Wales, more particularly Monmouthshire and Brecknockshire," iron ore was obtained from the coal measures of these counties, and the manner of extracting it is described.

In, or about, 1755 Mr. Anthony Bacon began to operate

[1] *The Geologist.*
[2] Williams, "History of Monmouthshire."
[3] "Fodinæ Regales."

at Merthyr Tydvil, and so extensive had his business become, that in 1783, when he retired, he had four ironworks to dispose of,—viz. Cyfarthfa, Penydarran, Dowlais, and Plymouth.

Mr. Coxe, in his "Historical Tour in Monmouthshire (1801)," says: "The masses of ore found near the surface were conveyed to the forges at Pontypool . . . it is a matter of wonder that these mineral treasures have been so long neglected."

In 1803 Mr. Malkin[1] wrote: "Mr. Crawshay's ironworks of Cyfarthfa, are now by far the largest in the kingdom."

Recent operations at Llantrissant Mines commenced about 1855.

PRODUCTION OF ORE SINCE 1857.

Year.	Limonite. Tons.	Clay Ironstone. Tons.
1857	24,300	1,013,941
1858	24,635	727,596
1859	42,200	607,558
1860	29,217	601,488
1861	41,557	504,148
1862	43,893	428,160
1863	54,613	365,404
1864	63,569	404,786
1865	64,437	323,305
1866	67,387	301,305
1867	73,624	427,562
1868	83,535	629,145
1869	82,871	632,130
1870	88,720	471,285
1871	83,324	886,390
1872	72,766	1,174,828
1873	53,155	890,771
1874	120,890	540,726
1875	100,290	495,840
1876	83,970	476,285
1877	77,320	367,316
1878	56,639	318,399
1879	53,811	299,000
1880	65,567	278,361

[1] "Antiquities of South Wales."

	Limonite. Tons.	Clay Ironstone. Tons.
1881	66,739	251,372
1882	39,800	204,882
1883	25,119	139,840
1884	12,479	89,937
1885	1,601	63,294
1886	14,968	60,092
1887	17,816	44,611
1888	15,029	41,616
1889	12,043	41,199
1890	9,423	40,293

Scotland. There does not appear to be any evidence of iron having been made here by either the Romans or by the Saxons.

In 1609 [1] it was proposed to erect ironworks in the Highlands, and to use the natural wood there for the purpose of smelting the ore, but an Act of Parliament prohibited this, on the ground that the waste of timber would be too great. Shortly afterwards, however, an ironworks seems to have been actually established, for in 1613 a proclamation was made by the Privy Council, restraining the export of iron ore out of the country, so that the enterprises of the new industry should not be hindered or disappointed.

In 1621 [2] "Sir George Hay, of Kinfauns, had permission to transport any iron made by him to any port or harbour of any burgh, notwithstanding the privileges or liberties formerly granted to the burghs."

About 1750 a furnace was erected at Goatfield and another at Bunawe near Loch Awe, both in Argyleshire. The latter is still occasionally in operation. According to Aiton,[3] the ore used here or some of it came from Muirkirk.

In 1760 Smeaton's improved blowing engine was first applied at Carron Ironworks.

[1] "Early Records relating to Mining in Scotland," by R.W. Cochrane-Patrick, 1878.

[2] *Ibid.*

[3] "General View of the Agriculture of the County of Ayr."

Pennant,[1] in 1767, refers to the Carron Ironworks, and says: "They are the greatest of the kind in Europe. They were formed about eight years ago."

In 1781 a furnace was erected at Wilsontown, and another in 1788, making a total of eight furnaces, in Scotland, in the latter year—four at Carron, two at Wilsontown, and two in Argyleshire.

In 1792, according to Sir John Sinclair,[2] there were five furnaces in operation at Carron.

In 1796[3] there were seventeen furnaces in the whole of Scotland, producing 16,086 tons a year. The following furnaces had been erected during the previous four years: Muirkirk (2), Omoa (2), Clyde (3), Devon (2).

The blackband ironstone was discovered by Mushet in 1801 when crossing the River Calder in the parish of old Monkland.

In 1806 there were twenty-seven furnaces in Scotland, capable of producing 22,840 tons a year, others having been commenced since 1796 at Calder (2), Shotts (1), Glenbuck (1), and Markinch (2), in Fifeshire; whilst the number of furnaces at Carron and Muirkirk had been increased.

In this year Gough writes: "Great plenty of iron ore is found near the wood of Dalbogie. A considerable ironwork has lately been erected at Wilsontown or Cleugh, near Carnwath, and another is erecting near Glasgow."

Little progress seems to have been made during the next seventeen years, for in 1823 the production of iron was only 24,500; but in 1825 the Monkland Iron Company erected their first furnace, adding a second in 1828 or 1829; and in 1830 the works at Gartsherrie were commenced. The production in this year was 37,500 tons, equal to about 112,500 tons of ore.

Between 1830 and 1855 the development of the iron-ore resources of this country made enormous strides, and the production was increased twenty-fold.

[1] "A Tour in Scotland."

[2] "Statistical Account of Scotland."

[3] Return made by Dr. McNab in opposition to a proposed tax on coals

PRODUCTION OF IRONSTONE SINCE 1855.

Year.	Tons.	Year.	Tons.
1855	2,400,000	1873	1,986,000
1856	2,201,250	1874	2,119,771
1857	2,500,000	1875	2,452,235
1858	2,312,000	1876	2,552,553
1859	2,225,000	1877	2,621,852
1860	2,150,000	1878	2,443,923
1861	1,975,000	1879	2,458,407
1862	1,500,000	1880	2,659,317
1863	1,500,000	1881	2,600,609
1864	1,950,000	1882	2,406,084
1865	1,470,000	1883	2,228,851
1866	1,587,000	1884	1,885,376
1867	1,264,800	1885	1,838,423
1868	1,250,000	1886	1,507,534
1869	1,950,000	1887	1,321,899
1870	1,980,000	1888	1,236,597
1871	1,975,000	1889	1,061,734
1872	1,978,000	1890	998,835

Ireland (County Antrim). Although the aluminous ores of Antrim were probably known at an early date, yet their economic importance does not appear to have been realised until about 1843. There was then an attempt made by Mr. Crommelin at Newton Crommelin, to smelt them on the spot by means of coke prepared from turf, but the attempt failed.[1] The ore worked at that time appears to have been "bole," the pisolitic ore not being known.

In 1861 Dr. Ritchie began to work these beds—then known as the Belfast Aluminous Ore—at Ballipallidy;[2] and in 1866 the late Mr. T. Fisher, of Barrow-in-Furness, commenced operations at Glenravel. This was practically the beginning of the present Antrim iron-ore trade. Since then numerous other individuals and companies have entered the field; and the progress made by them will perhaps be better indicated by a table of the annual output than by a lengthened description:—

[1] Dr. J. F. Hodges, Belfast Natural History and Philosophical Society, November 1875.

[2] Belfast and Ballymena Railway, opened April 11th, 1848.

Year.			Tons.	Year.			Tons.
1861	...	...	165	1876	...	...	115,579
1862	...	..	10,431	1877	...	...	152,495
1863	...	...	15,937	1878	...	...	156,834
1864	...	...	41,839	1879	...	...	155,833
1865	...	...	14,117	1880	...	...	239,325
1866	...	...	15,704	1881	...	...	199,863
1867	...	...	24,416	1882	...	...	189,724
1868	...	...	24,469	1883	...	...	146,452
1869	...	...	22,058	1884	...	...	102,496
1870	...	...	52,600	1885	...	...	107,646
1871	...	...	93,326	1886	...	...	101,570
1872	...	...	146,500	1887	...	...	135,389
1873	...	...	113,870	1888	...	...	129,235
1874	...	...	140,360	1889	...	...	164,686
1875	...	...	128,302	1890	...	...	159,268

PART II.

THE GEOLOGICAL POSITION, FORM, AND INNER NATURE OF IRON-ORE DEPOSITS.

CHAPTER I.

INTRODUCTORY.

THE principal iron ores of commerce are oxides and carbonates. As they occur in Great Britain and Ireland they may be sub-divided as under:—

OXIDES.

Magnetite (Fe_3O_4), commonly called magnetic iron ore, and consisting of oxygen 27·6 and iron 72·4 = 100; or, sesquioxide of iron 68·97 and protoxide of iron 31·03 = 100. Its colour and streak are iron black, hardness 5·5—6·5, specific gravity 4·9—5·2; and it is strongly magnetic, sometimes polar.

Hæmatite (Fe_2O_3). The variety commonly called *red* hæmatite is that most used for metallurgical purposes. Its composition is, iron 70, oxygen 30 = 100, hardness 5·5—6·5, specific gravity 4·2—5·3. Its colour is red to bluish purple; streak, red to reddish brown.

Limonite ($2\ Fe_2O_3,\ 3H_2O$). There are several varieties, but that usually known as *brown* hæmatite is principally used in iron making. It consists of sesquioxide of iron 85·6, and water 14·4 = 100. Its hardness varies from 3·6—4. Specific gravity 3·6—4. Usual colours, brown or brownish-yellow, sometimes nearly black on the exterior and shining; streak, yellowish-brown.

CARBONATES.

Siderite (Fe_1Co_3), known also as spathic or spathose ironore (some of the more impure descriptions are called clay ironstone, clayband, and blackband ironstone). It contains

protoxide of iron 62·1 (= iron 77·7̇7̇, oxygen 22·2̇2̇ = 100), carbonic acid 37·9 = 100. Its hardness is 3·5—4·5, and specific gravity 3·7—3·9. Colours, white, ash-grey, brown, reddish-brown; streak, white.

None of these ores are perhaps ever met with in the state of purity here indicated; certainly not in any quantity. Usually they contain a greater or less proportion of ordinary rock-forming material, as will be seen from the analyses later on. The extent to which this foreign matter is present determines the value of the ore to the metallurgist.

Iron is one of the most abundant metallic minerals in nature, but as a rule it is so mixed up with other matter as to be altogether unavailable to the iron-maker. The positions, both vertically and laterally, or geologically and topographically, in which it is sufficiently concentrated to be of any economic importance, at present, are comparatively few; although we, in Britain, have perhaps a larger number, and a greater extent of such accumulations, than has yet been found in any similar area in the world.

The opposite table shows the geological horizon on which most of the workable iron ores in Great Britain and Ireland are found. Iron ore, not included in this table, is found, in granite, both in Cumberland and Cornwall. In the former county the granite comes to the surface through lower Silurians and in the latter through Devonian Rocks.

From our present standpoint iron ores may be looked at in three different ways:—

1. As to Geological position.
2. Geographical distribution.
3. Mineralogical characteristics.

In grouping the deposits for description, it tends to brevity, as well as to a clearer conception, to view some of them in one way, and some in another, according to circumstances. That, therefore, is the manner in which they will be dealt with in this part of the work.

Geological and Topographical Distribution of Ore.

Geological Systems.	Formations containing Workable Ore.	Variety of Ore.	Localities in which the Ores are worked.
Miocene { Upper ...	... ...	...	... ...
Lower ...	Basalt	Limonite	County Antrim, Ireland.
Eocene	... ...	...	... ...
Cretaceous { Upper	... ...	...	... ...
Lower	Lower Greensand Middle Neocomian	Limonite Do.	Seend, Wiltshire. Tealby and Claxby, Lincolnshire. Weald of Kent and Sussex (not now worked).
Oolite { Upper ...	... ...	...	... ...
Middle ...	Coral Rag	Siderite and Limonite	Westbury, Wilts.
Lower ...	Northampton Sand	Do. Magnetite	Cleveland, Northamptonshire, Lincolnshire, Rutlandshire. Rosedale, Yorkshire.
Lias { Upper ...	... ...	...	... ...
Middle ...	Marlstone Rock Beds	Siderite and Limonite	Cleveland, Lincolnshire, Leicestershire and Oxfordshire.
Lower ...	... ...	Limonite and Siderite	Frodingham, Lincolnshire.
Trias...	... ...	...	... ...
Permian	... ...	...	... ...
Carboniferous ...	Coal Measures	Siderite	Scotland, Yorkshire, Derbyshire, Staffordshire. Shropshire, Warwickshire, South Wales.
	Yoredale Rocks	Siderite and Limonite	Weardale and Alston Moor.
	Carboniferous Limestone	Siderite Limonite Hæmatite	Northumberland. { Forest of Dean and Glamorganshire. { West Cumberland and Furness.
Devonian { Upper	... ...	...	... ...
Middle	... ...	Siderite } Limonite } Hæmatite Magnetite	Somersetshire } Devonshire. Cornwall.
Lower	... ...	...	... ...
Silurian { Upper ...	... ...	...	... ...
Lower ...	Coniston Limestone Skiddaw Slates	Hæmatite Do.	Water Blean, Cumberland. Knockmurton and Kelton Fell, Cumberland.
Cambrian	... ...	...	... ...

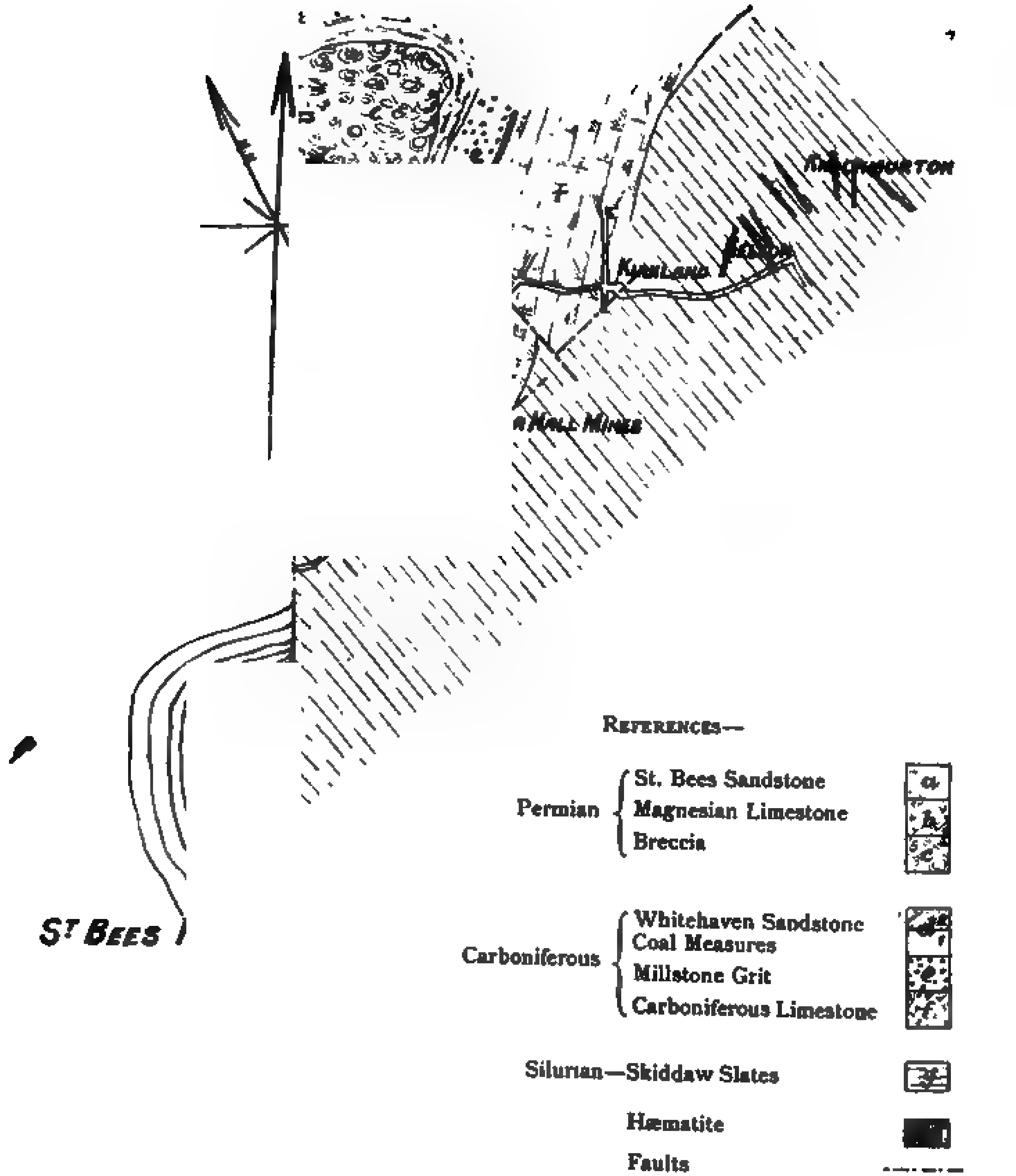
CHAPTER II.

THE HÆMATITE DEPOSITS OF WEST CUMBERLAND AND FURNESS.

PERHAPS there are no districts of equal importance in the whole of the British Isles which have received so little attention from men of science as the hæmatite districts of West Cumberland and Furness:—

The following list includes perhaps all that has been written except mere incidental references.

1. "A Glance at the Geology of Low Furness, Lancashire," by E. W. Binney. *Proceedings of the Manchester Literary and Philosophical Society*. 1847.
2. "On the Hæmatite Ores of North Lancashire and West Cumberland," by Professor J. Phillips and R. Barker. *Reports of the British Association for* 1858.
3. "The Hæmatite Mines of the Ulverston District," by J. C. Greenwell. *Transactions of the Manchester Geological Society*, vol. v., p. 248.
4. "The Age of the Hæmatite iron Deposits of Furness," by E. W. Binney. *Proceedings of the Manchester Literary and Philosophical Society*, 1867.
5. "The Hæmatite Iron-ore Deposits of Whitehaven. Notes on the Aldby Limestone, Cleator Moor," by W. Brockbank. *Proceedings of the Manchester Literary and Philosophical Society*, 1868.
6. "Geological Notes on Iron Ores," by G. A. Moon, Whitehaven, 1868.



inch to a mile.)

7. "Facts developed by the working of Hæmatite Iron Ores in the Ulverston and Whitehaven Districts, from 1844 to 1871," by T. Ainsworth. *Chemical News*, vol. xxiv., pp. 104-6.
8. "On the Geology of the North Lancashire and Cumberland Iron-ore Districts," by P. Würzburger. *Proceedings of the Iron and Steel Institute*, 1874.
9. "The Hæmatite Iron Mines of the Furness District," by J. L. Shaw. *Proceedings of the Institute of Mechanical Engineers*, 1880.

The following six papers are by the Author, J. D. Kendall:—

10. "The Hæmatite Deposits of Whitehaven and Furness," *Colliery Guardian*, vol. xxviii., 1874.
11. "Hæmatite in the Silurians," *Quarterly Journal of the Geological Society*, 1875.
12. "The Hæmatite Deposits of Whitehaven and Furness," *Transactions of the Manchester Geological Society*, vol. xiii.
13. "The Hæmatite Deposits of West Cumberland," *Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1879.
14. "The Hæmatite Deposits of Furness," *Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1882.
15. The Mineral Veins of the Lake District," *Transactions of the Manchester Geological Society*, 1884.

Those parts of West Cumberland and Furness in which hæmatite deposits mainly occur may be roughly described as a belt of country of varying width, extending along the sea coast from Whitehaven on the North for a distance of about thirty-three miles, its greatest width being about eight miles. Along the landward edge of this belt stand some of the western mountains of the lake country, which vary in appearance according to the nature of the rocks of which they are formed; being sometimes of a rough and rugged outline, at others smooth and regular. Between this mountainous tract and the

sea the ground is low and gently undulating, seldom rising above four hundred feet, and being mostly below the hundred and fifty feet contour.

The hæmatite deposits hitherto worked occur in the centre and at the extreme ends of this belt, those in the north being about Kelton, Salter, Winder, Frizington, Cleator Moor, Bigrigg, and Egremont, and those in the south at Silecroft, Hodbarrow, Water Blean, and in Furness. The deposits in the central part of the belt occur in the hills about Eskdale. Plate I. is a geological map of the northern area.

Stratigraphical and Lithological Details.

The geological systems represented in these districts are not numerous, but they are very well developed. The relations of the various members composing them are shown in the following table :—

	SUPERFICIAL DEPOSITS.	
Permian System.	Saint Bees Sandstone. Magnesian Limestone. Breccia.	
	UNCONFORMITY.	
Carboniferous System.	Yoredale rocks. Carboniferous Limestone. Lower Limestone Shale. Conglomerate.	
	UNCONFORMITY.	
Silurian System.	Coniston grits and flags. Coniston Limestone.	
	Volcanic rocks of Borrowdale. Skiddaw slate.	Traversed by Granite and Syenite.

Granite is found only in one locality. It is known as the Eskdale granite, from the fact that it is mainly found in that neighbourhood. Its colour varies from grey to red, according to the colour of its felspar. Several deposits of hæmatite have

been worked in it, but only one or two to any extent. These are near Boot in Eskdale. The composition of this rock, as given in the "Survey Memoir of the Lake District" (northern part), is as follows :—

Silica	73·573
Alumina	13·750
Lime	1·064
Magnesia	·396
Potash	3·512
Soda	4·315
Ferrous oxide	2·103
Ferric oxide	·615
Phosphoric acid	·012
Sulphuric acid	—
Carbonic acid	trace
Water (loss on ignition)	·660
Total	100·000

Syenite occurs in the hills about Ennerdale. The prevailing colour is pale red. Hæmatite has been worked in it to a small extent at Crag Fell; but the rock is too hard to allow the narrow veins which occur in it there to be worked profitably.

The Skiddaw Slate series forms much of the high ground near Ennerdale, in the north-east portion of the district, the mountain of Black Comb in Millom, and it also occupies a small area in Furness. They may be looked upon as the basement rocks of the district. They consist of bluish, greenish, and purply-grey mudstones and greyish grits, which are sometimes spotted with purple or brown. None of these rocks are much used for economic purposes; partly on account of the ease with which the atmosphere and other meteoric agencies act upon them, and partly owing to their being so much split up by joints. Their thickness is uncertain, but has been variously estimated at from five thousand to ten thousand feet. Owing, however, to the great similarity of the beds, and the consequent difficulty of detecting faults, their real thickness is probably less. For the same reason the suc-

cession of beds has not yet been accurately ascertained, so that we cannot be quite sure of the horizon of many of them. They are generally inclined at high angles, which vary greatly both in direction and amount. In ten square yards of ground they may be seen to dip to the four principal points of the compass, at angles with the horizon varying from 45° to 80°. They are, moreover, much split up by joints, which range themselves into two principal sets—one set running about 15° north-east and south-west, the other about 37° north-west and south-east. Sometimes the dip and strike of the strata correspond with one of these sets of joints. The rocks then have a flaggy appearance, but more generally the beds are intersected by both sets, in which case the rocks, owing to their thin bedding, have a very broken appearance. Hæmatite has been found in this group at several places, but has been worked extensively at Kelton Fell and Knockmurton only.

The composition of the Skiddaw Slate as it exists at Red Pike, not far from Knockmurton, is given in the "Lake District Memoir" as follows :—

Silica	54·480
Alumina	20·720
Lime	1·624
Magnesia	1·946
Potash	3·203
Soda	6·217
Ferrous oxide	8·188
Ferric oxide	·988
Phosphoric acid	·569
Sulphuric acid	trace
Carbonic acid	trace
Carbonaceous matter	·361
Water	1·704
Total	100·000

Borrowdale Series. The volcanic lavas and ashes of this series, usually known as the green slates and porphyries, form the remaining portion of the high ground on the eastern side of the district. It is through these rocks that the Eskdale

granite last rises in its passage to the surface. Hæmatite has been found in the series at a great many places, but only in very small quantity.

Coniston Series. These consist of Coniston limestone, Coniston grits, and Coniston flags, and occupy but a small area in the southern part of the district. The limestone formation occurs in some places as one solid bed of limestone; in others it is found in somewhat thinner beds, which are interstratified with limy shales. It is generally of a deep blue-grey colour, and some of the more shaly portions weather very much. Usually it is inclined at very high angles, sometimes being nearly on end. The grits and flags are of a very hard and durable nature, and are much used for building purposes. They occur alternately throughout the upper part of the series. Hæmatite is not abundant in these rocks; but in the limestone at Water Blean a deposit was worked interruptedly for a few years, the ore being used mostly for colouring purposes. The writer is not aware that any hæmatite has been found in the grits and flags.

Carboniferous Limestone Series. This is the most important group of rocks in these districts, as in it are found those immense deposits of hæmatite, through which the districts have become so famous. It rests transgressively on the denuded edges of the Silurians, lying sometimes on the Skiddaw slate, as in the northern part of the district (see Plate I.). At other times it may be found upon the Borrowdale or Coniston series, as between Silecroft and Millom, and also in Furness.

Whitehaven District.

At the Whitehaven end of the district it generally dips to the west or north-west at angles varying from twelve to thirty degrees with the horizon, and consists of alternations of limestone, sandstone, and shale, the first predominating. From the correlation of a great number of sections which have been obtained, either by boring or sinking, between Rowrah and Egremont, the writer considers that it may be divided into seven distinct beds of limestone, as described below. The

bottom bed of the formation is shale, mostly of a red colour, but sometimes grey, at others nearly black. Occasionally, as in the neighbourhood of Egremont, it has, in some of its layers near the bottom, quite a conglomeratic character. The shale bed is very thin in the neighbourhood of Yeathouse and Salter; but from there it seems to thicken gradually both towards Lamplugh on the one hand, and Egremont on the other. Everywhere within the Whitehaven hæmatite district, that is to say, over an area of about seven square miles, the shale forms the base of the carboniferous rocks, and reposes on the upturned and eroded edges of the Skiddaw slate; facts which go to show that the carboniferous rocks of that area were deposited on a plane of marine denudation.

The Seventh or Bottom Limestone contains a few partings of shale, and varies in thickness from 40 to 182 feet. So far as proved, this bed is thinnest at Lamplugh, and thickens gradually towards Egremont. Within the more important parts of the hæmatite area the variations in thickness are less than those just mentioned, there being a rapid thinning of the bed towards the north-east after leaving Eskett. This bed is separated from the sixth limestone by a few variable shale beds, which in the neighbourhood of Egremont become so thin, that the sixth and seventh limestones may there be said to form one bed, although towards the north-east they are distinctly separated.

The Sixth Limestone also contains a few thin partings of shale, and varies in thickness from 54 to 70 feet, except at Lamplugh, where it reaches the uncommon thickness of 105 feet. Between the sixth and fifth limestones there is from 14 to 24 feet of shale, or shale and sandstone, and sometimes thin beds of limestone. These dividing beds are more variable than those separating the higher beds of limestone, but still they are sufficiently persistent to be always traceable.

Fifth Limestone. This bed, like the last, is split up by thin beds of shale, but they are very inconstant. It ranges in thickness from 50 to 70 feet. Over this limestone there is from 14 to 24 feet of shale usually, but occasionally it is shale and sandstone.

Fourth or Clints Limestone. This bed varies from 235 to 310 feet in thickness. In some parts of the district it consists almost entirely of limestone, but in others it is split up by thin beds of shale, which, however, are very inconstant; generally they may be said to increase in number and thickness towards the north-east. Some parts of the limestone of this bed are very silicious, the rock then assuming that character which is locally known as "Whirlstone." Towards the north-east sandy beds appear in it, as at Winder.

Third Limestone. This bed consists entirely of limestone, and ranges in thickness from 10 to 16 feet. In the writer's paper on the "Hæmatite Deposits of West Cumberland," it was included with the one immediately below (now the fourth limestone), from which it is divided by only 2 to 6 feet of shale; but as this shale bed, although thin, is very persistent, it is more convenient, as well as more correct, to consider the limestones between which it lies as separate beds. Between the third and second limestones there is from 40 to 60 feet of rocks, which are in some places entirely sandstone, at others they are all shale, but more frequently it is found that they consist of sandstone and shale together.

Second Limestone also consists of one mass of limestone, and varies in thickness from 14 to 24 feet. Between the second and first limestones sandstones and shale intervene. They vary in thickness from 10 to 14 feet.

First, or Top, or Langhorn Limestone, consists of one mass of limestone, varying in thickness from 30 to 60 feet. Sometimes the upper part of the bed (especially about Winder) is silicified, and its thickness, as shown in journals of boreholes, then appears to be less than it really is. As a rule, the first limestone is thicker about Bigrigg than in the Winder locality; but on the other hand, the third limestone is thicker at Winder than about Bigrigg. The other beds do not vary much in the two localities. The greatest thickness known to the author as having been proved at one point is 758 feet; this was at Winder Gill. The whole seven beds were passed through, the lowest one resting upon the

Skiddaw slate, except for the thin shales—the equivalent of the lower limestone shale. At Bigrigg the thickness has been proved to be about 620 feet.

The strata separating the various beds of limestone follow no regular order in the different parts of the district. This is illustrated by the thick mass separating the third and fourth limestones. About Winder this bed consists mainly of dark shale. At Bigrigg it is nearly all sandstone, whilst between these two places it is made up of both shale and sandstone in varying proportions, the sandstone becoming thinner, and the shale thicker, as Winder is approached.

In a paper on the Carboniferous Rocks of Cumberland and North Lancashire, or Furness,[1] the author has correlated these limestones with the rocks of Alston Moor and Furness as under :—

	Alston Moor.	Whitehaven.	Furness.
Yoredale Rocks.	Felltop limestone	First limestone	Yoredale rocks.
	Little ,,	Third ,,	
	Great ,,	Fourth ,,	
	Fourfathom ,,		
	Three Yard ,,		
	Five ,, ,,	Fifth ,,	
	Scar ,,		
	Tyne Bottom ,,		
Mountain limestone ...		Sixth ,,	Thick limestone.
		Seventh ,,	
		Red shales ...	Red shales and limestones.

COMPOSITION OF THE LIMESTONE.

	Birks.	Salter Hall.
Carbonate of lime	94·93	97·44
Peroxide of iron	2·43	·46
Alumina	·32	
Insoluble silicious matter ...	1·85	·48
Phosphoric acid	Traces	·03
Sulphuric acid		·07
Magnesia, etc.	·47	·13
Organic matter and water	...	1·27
Total	100·00	99·88

[1] *Transactions of North of England Institute of Mining and Mechanical Engineers*, vol. xxxiv.

As already stated, hæmatite occurs very abundantly in these rocks. It has been found in each of the seven beds, and deposits of more or less importance have been, or are now being, worked in them. A few of these deposits may perhaps be conveniently mentioned here.

In the first or Langhorn limestone there are the old Winder Gill deposit, the flat ore at Agnes pit, the Parkside and Crossgill deposit, the Crowgarth deposit, the top deposits at Bigrigg, part of the Woodend deposits, and the upper beds at Pallaflat and Southam.

In the second limestone there are the second deposits at Bigrigg, Pallaflat, Southam, and Lord Leconfield's Bigrigg pits.

In the third and fourth limestones there are the Wyndham pit deposit at Bigrigg, some of the Woodend deposits, some of the Montreal deposits, the ore worked by the Mowbray Company's No. 2 pit, the Salter Hall, Postlethwaite's Eskett, and Winder Gill deposit.

In the fifth limestone there are Eskett Park No. 7 pit deposit, and the upper deposit worked by the Crossfield Company's No. 3 pit.

In the sixth limestone there is the deposit worked by the Eskett Park Nos. 5, 8, and 9 pits, and the upper deposit worked by Postlethwaite's Eskett No. 3 pit.

In the seventh or bottom limestone there are the lower deposit worked by the Crossfield Company's No. 3 pit, the deposits worked by the Nos. 10 and 11 pits of Messrs. Bain & Company at Woodend, lower deposit in upside of fault at Postlethwaite's Eskett pits, and the ore worked by Longlands, Ehen, Gillfoot Park, and Wyndham Company's pits.

From this it will be seen that there is a very wide difference in the *geological* level of the deposits. Owing, however, to the tilted position of the limestone, the way in which it is dislocated by faults and the extent to which it has been denuded, this difference in geological level does not affect their *absolute* level, as many of the deposits in the lower beds are quite as near the surface as those which occur in the higher beds. For instance, at Todholes, the ore found in the Bottom lime-

stone was so near the surface as to be worked by "open cast," and, as will hereafter be seen, deposits of ore are not unfrequently found on the same absolute level (but on opposite sides of a fault) which are in totally different beds of limestone.

FURNESS.

The details of the carboniferous rocks in Furness are as follow:—

1. Conglomerate. This rock rests on the Silurians, but occupies a very small area on the surface; it consists of rounded fragments of older rocks, firmly cemented together in such a way that it has the appearance of a hardened boulder clay. It was at one time supposed to belong to the Devonians.

2. Shales and Limestones. Overlying the conglomerate there is a great thickness of shale, with numerous bands of limestone. The latter increase in thickness toward the upper part of the formation, and gradually introduce the great mass of limestone by which they are overlaid. The following is the journal of a borehole put down through these rocks between Dunnerholm and Ireleth:—

	Fms.	Ft.	In.
Sand, clay, and pinnel[1]	29	4	6
Hard limestone	0	4	8
Red limy shale	0	1	2
Limestone	0	2	0
Red limy shale	0	2	3
Limestone	0	1	6
Red limy shale	1	2	6
Limestone	0	1	11
Red limy shale	0	3	0
Limestone	0	5	5
Red limy shale	0	1	3
Brown limestone	0	2	6
Red limy shale	1	0	3
Brown limestone	1	1	5
Hard limy shale	0	1	3

[1] Local name for Boulder Clay.

	Fms.	Ft.	In.
Brown limestone	0	1	3
Hard sandy limy shale	1	0	2
Brown limestone	0	0	5
Hard sandy limy shale	0	5	8
Hard bastard limestone	0	3	9
Red limy shale	0	3	6
Hard bastard limestone	0	1	0
Red limy shale	2	1	6
Bastard limestone	1	0	3
Red limy shale	0	0	6
Bastard limestone	0	1	4
Red limy shale	0	3	9
Bastard limestone	0	1	6
Red limy shale	0	0	8
Bastard limestone	0	1	3
Red limy shale	1	2	0
Bastard limestone	0	2	11
Red limy shale	0	2	0
Bastard limestone	0	1	0
Red limy shale	0	1	0
White limestone	0	0	4
Red limy shale	0	0	10
White limestone	0	0	4
Red limy shale	0	0	8
Red limestone	0	4	8
Limy shale	0	1	7
Red limestone	0	0	6
Limy shale	0	1	6
Hard limestone	0	3	5
Red limy shale	0	4	6
Hard limestone	0	2	0
Red limy shale	0	5	6
Hard limestone	0	0	9
Red limy shale	0	2	0
Hard limestone	0	2	0
Red limy shale	0	1	0
Hard limestone	0	1	0
Red limy shale	0	0	9
Hard limestone	0	0	3
Red limy shale	0	1	9
Hard limestone	0	1	1
Red limy shale	0	1	9
Hard limestone	0	0	9

	Fms.	Ft.	In.
Red limy shale	0	4	6
Hard limestone	0	0	11
Red limy shale	0	2	1
Hard limestone	0	1	9
Red limy shale	0	1	6
Hard limestone	0	0	11
Red limy shale	0	0	10
Hard limestone	0	3	11
Red limy shale	2	1	6
Hard limestone	0	5	8
Red limy shale	1	0	2
Hard limestone	0	1	8
Red limy shale	2	1	7
Limestone	0	0	8
Red limy shale	1	4	3
Limestone	0	0	8
Red limy shale	0	2	9
Limestone	0	0	3
Red limy shale	0	5	3
Limestone	0	1	0
Red limy shale	1	2	0
Hard limestone	0	2	1
Red limy shale	0	2	0
Hard limestone	0	1	8
Red limy shale	0	4	3
Hard limestone	0	1	9
Red limy shale	0	2	8
Hard limestone	0	1	9
Red limy shale	1	1	0
Red limestone	0	0	9
Red limy shale	0	1	7
Red limestone	0	0	6
Red limy shale	0	1	0
Red limestone	0	1	6
Red limy shale	1	4	8
Soft red and white parting	0	3	1
Hard red shale	0	1	5
Hard red limestone	0	3	2
Red limy shale	0	4	7
Red limestone	0	0	9
Red limy shale	9	5	1
Bastard limestone	1	3	9
Red limy shale	2	3	10

	Fms.	Ft.	In.
Red shale	5	5	4
Red bastard limestone	1	1	11
Red shale	2	1	9
Red bastard limestone	1	0	6
Red shale	1	4	10
Red bastard limestone	0	5	9
Red shale	2	4	5
Bastard limestone	0	3	11
Red shale	1	4	3
Bastard limestone	0	0	9
Red shale	5	5	6
Bastard limestone	0	0	6
Red shale	2	0	10
Total	119	0	10

These shales and the underlying conglomerate appear to be the equivalent of the red shales (sometimes conglomeratic), which occur at the base of the limestone series in the Whitehaven district.

8. Carboniferous Limestone. As in West Cumberland, so in Furness, this is the most important formation of all, so far as the present subject is concerned, as it is in this that all the hæmatite deposits occur. It consists almost entirely of limestone, there being only a few thin beds of shale, which seldom exceed an inch or two in thickness. The thickest beds of shale occur near the bottom and top, that is, near the underlying shales just noticed, and the overlying Yoredales presently to be described. The total thickness of the formation is not known, but it is certainly over 940 feet, as that thickness has been pierced by a borehole at Windhills near Stainton. The following is a journal of that bore :—

	Fms.	Ft.	In.
Surface	5	1	0
YOREDALE ROCKS.			
Blue whirlstone	0	5	6
Grey sandstone	0	5	0
Blue shale	6	3	0
Grey sandstone	0	3	0

	Fms.	Ft.	In.
Blue shale	8	0	0
White sandstone	0	2	0
Black shale	1	3	6
Shale and sandstone	2	0	0
Sandstone	2	3	0
Black shale	1	2	0
Sandstone	1	4	0
Black shale	29	2	6
Sandstone and shale	0	5	6
Black shale	40	4	6
Bastard limestone	1	4	6
Black shale	2	1	4
Grey limestone	0	3	2
Black shale	2	0	6
Limestone	1	0	6
Black shale	1	3	0
Fossil shale	5	4	6
Grey limestone	0	2	0
Bastard limestone	0	4	0
Shale and limestone	1	4	0
Black shale	4	0	0
Limestone	2	2	0
Black shale	1	3	0
Red joint	0	0	6
Limestone	0	0	6
Black shale	1	1	0

CARBONIFEROUS LIMESTONE.

Brown limestone	0	3	6
Limestone	1	0	6
Black shale	0	1	0
Loughhole	0	1	0
Bastard limestone	0	5	6
Shale and limestone	1	3	6
Limestone	0	3	0
Shale (fossiliferous)	0	5	6
Limestone	5	2	2
Shale (fossiliferous)	1	4	4
Limestone	0	5	0
Grey sandstone	0	2	0
Shale	1	2	6
Black shale	0	5	0
Shale and limestone	0	3	0

	Fms.	Ft.	In.
Ore and limestone	0	3	0
Grey limestone	3	3	9
Limestone mixed with white clay	2	1	0
Grey limestone	3	3	6
Light-grey limestone	41	2	3
Clay mixed with ore	0	2	8
Dark-grey limestone, streaks of ore	0	5	0
Limestone	66	0	11
Grey limestone marked with brown joints ...	0	2	11
Limestone	21	4	0
Total depth	286	5	6

There being no beds of marked lithological character in the formation it is impossible to arrive at the thickness by correlation. The same difficulty is met with in fixing the exact geological level of many of the hæmatite deposits. It is easy to show that the Askam deposit is in the lower beds of the formation, and that the Stank and Stainton deposits are in the upper beds; but it is not possible at present to say in which beds the Lindal Cote deposit is, except that it is in the middle beds; but whether it is nearer the top or bottom cannot be said, and there are many cases of this kind in the district. For the same reason it is equally difficult to trace in these rocks the existence of faults. It is sometimes possible to detect them in the mine, but the amount of their throw cannot even then be determined, as will be readily understood.

The thick limestones and the Yoredales correspond respectively to the sixth and seventh limestones, and the first, second, third, fourth, and fifth limestones of the Whitehaven district.

As in the Whitehaven district so here, the *absolute* level of a deposit is altogether independent of its *geological* level, some deposits in the bottom beds of limestone being much shallower or nearer the surface than others that are in the upper beds of limestone.

The dip of the rocks in the western part of the district is to the west, at angles varying from 20° to 45°. In the eastern

part of the district the general dip is to the south-east, at angles of 5° to 15°.

In searching for hæmatite in Furness some very peculiar sections are occasionally met with. That given below may be taken as an example :—

JOURNAL OF BOREHOLE PUT DOWN AT CROSSGATES.

	Ft.	In.	Ft.	In.
Soil	2	0		
Gravel and clay	24	0		
Decomposed limestone	17	0	43	0
Yellow clay mixed with iron ore ...	4	0		
Black mould	4	0		
Iron ore (dark coloured)	2	0		
Black mould mixed with iron ore ...	6	0	16	0
Iron ore	8	0		
Decomposed limestone	7	0	15	0
Black woody deposit			12	0
Decomposed limestone			6	0
Black mould and wood	2	0		
Yellow clay mixed with ore	16	0		
Black mould mixed with ore	14	0		
" " mixed with ore and limestone	3	0	35	0
Total depth			127	0

The wood found in this and similar sections is exogenous, and belongs to recent species, which proves clearly that it, at any rate, and presumably the material in which it is embedded, has been recently introduced. The three masses of clay and black mould mixed with iron ore in the above section may therefore be taken to be filled "loughs" or caverns. Many of the caverns found in the district contain a large quantity of clay, also pieces of hæmatite and other materials. If they were *filled* with these materials a section of them would not be very different from that of the borehole given above.

The "backs" or vertical joints in the limestone have the

following directions, one set bearing about 25° north-west and south-east, the other being nearly east and west; and it is worthy of mention that all the caverns in the district have one or other of these directions where they are not interfered with by faults. The large cavern which was discovered at Stainton about eleven years ago illustrates this observation very well. The length of the cave is about 230 yards, and although it makes numerous turns in the course of its length, it invariably follows one or other of the two sets of joints in the limestone, as is easily ascertained, for these joints can be seen quite distinctly in the roof of the cavern.

The composition of the limestone is variable, sometimes being very silicious, much more so than in No. 3 analysis below. Where it has been worked for fluxing purposes it is very pure, as shown in Analyses Nos. 1 and 2.

	1 STAINTON.	2 GOLDMIRE.	3 HAUME.
Carbonate of lime	95·00	98·00	89·00
" magnesia ...	4·20	·70	2·93
Silica	·50	·83	3·24
Oxide of iron and alumina ...	·30	·68	2·60
Total	100·00	100·21	97·77

The specific gravity may be taken to be about 2·72 on an average.

4. *Yoredale Rocks.* Overlying the limestone first described, and terminating the carboniferous system upwards in Furness, there is a large mass of dark-coloured shales, interbedded in their lower part with one or two beds of limestone, and near the top with a few beds of sandstone. These rocks were formerly supposed to belong to the coal-measures; in fact, a few years ago a shaft was sunk near Stank in the hope of finding coal. This shaft, after passing through about ninety fathoms of rocks belonging to the Yoredales, came upon a very fine deposit of hæmatite in the carboniferous limestone below. The greatest thickness of Yoredale rocks yet proved was near Gleaston, where, by the Diamond boring machine, about 1,410

feet were pierced, after passing through 590 feet of Saint Bees sandstone and shales, and 65 feet of Magnesian limestone. The upper part of the Windhills borehole already given was in these rocks, and it may be taken as a fairly representative section of them. Near Gleaston there is a small patch of greenstone protruding through the carboniferous rocks. What was probably a branch from it was passed through in the midst of the Yoredale rocks by the deep borehole just alluded to. The deep borehole at Rampside also pierced a similar rock in the red sandstone.

In Millom the series has the same form of development as in Furness, but the Yoredales are wanting.

As previously mentioned, the Author considers that the first, second, third, fourth, and fifth limestones of the Whitehaven district are the equivalent of the Yoredales of Furness.

The Millstone Grit Series occurs only in the Whitehaven area (see Plate I.). It consists of alternations of shales and sandstones, the beds of which are very variable in thickness, and not very persistent. The bottom bed—that resting on the first limestone—is, however, an exception, as, so far as the writer knows, it is invariably a sandstone, with mostly a thin parting of shale between it and the limestone below. The average thickness of the grits may be taken at about 155 feet.

Very little hæmatite occurs in these rocks, although in places it has been worked in connection with the deposits in the top limestone. From these latter deposits it runs in thin strings into the bottom bed of sandstone which forms the base of the grits. It also occurs in nodules and thin beds in the shales. The writer has found in these nodules fossil shells, converted into hæmatite. The ore in some parts also contains a large proportion of lime, in fact, it is mixed with limestone here and there, which changes by insensible degrees into the are adjoining it.

The Coal Measures also are found only about Whitehaven (Plate I.). They are divisible into two parts, which are unconformable to one another.

First, the lower portion, which is made up of alternations of sandstones and dark-coloured shales, amidst which occur numerous bands of fire clay, coal, and clayband ironstone. The greatest thickness of this portion of the coal-measures is about 1,300 feet, in which there are at least 26 seams of coal. It forms by far the largest part of the coal-measures, and may be looked upon as the productive part of the Cumberland coal-field.

Second, the upper portion of the series, called the Whitehaven sandstone, which consists of alternations of reddish and dark shales, and purple, grey, and white sandstones. In the dark shales there are several coal seams. The sandstones usually contain a number of plant-like remains and clayey nodules, both of which are highly charged with peroxide of iron. In the beds of sandstone near the base of the formation grains of white quartz are occasionally found as large as a good-sized pea, which are in some cases scattered sparsely through the sandstone, whilst in others they are so closely packed as to give it the appearance of a breccia. In some places, between the interstices of the rock, there is a considerable quantity of specular iron in minute scales. In the same beds nodules of compact hæmatite are also met with.

The extent of the unconformity existing between the two parts of the group may be judged from the fact that, at Croft Pit, the Whitehaven sandstone overlies the whole of the lower coal-measures, whilst at Rowrah, eight miles off, it is down upon the millstone grit.

In this group, hæmatite has only been found in workable quantity at Millyeat, in the Whitehaven sandstone series. Its existence in those rocks has a very important bearing on much that has hereafter to be said, so that it is proposed to give a section to show the succession of beds. Unfortunately, information of this sort is very scarce where it would be most desirable to have it. The only section that has come to the Author's knowledge, obtained at one point, is the journal of a borehole that was put down in search of this hæmatite, between Millyeat and Weddiker. It is as follows :—

	Fms.	Ft.	In.	Fms.	Ft.	In.
1. Superficial deposits	0	3	0	11	0	0
2. Breccia (Permian)	10	3	0			
3. Grey sandstone	1	5	0			
4. Red shale	2	1	0			
5. Grey sandstone	0	2	0			
6. Red shale	9	0	8			
7. " " with iron ribs ...	7	1	2			
8. Sandstone	0	2	6			
9. Red and white shale	0	1	3			
10. Sandstone	0	2	6			
11. Red shale	3	0	10			
12. Sandstone	0	2	0			
13. Red sandy shale	1	2	4			
				37	3	3
Thickness of Whitehaven sandstone passed through ...				26	3	3

Breccia. This, the lowest representative of the Permians in these districts, consists of fragments—some angular, others rounded—of all the rocks that have just been described. As previously shown, it is unconformable to all the underlying formations. Its thickness seems to increase as the hills are approached. In Demesne Gill, on the road from Whitehaven to St. Bees, where it is overlaid by the magnesian limestone, it is only 9 feet thick, whilst at Winder, with a denuded top, it has been proved to be 400 feet.

Hæmatite occurs in this formation in the form of rounded and angular fragments mixed up promiscuously with the other rocks. At times these hæmatite fragments are very numerous, and the miners then call the formation "iron gravel," or "gravel ore." It has in one or two cases actually been worked for the iron it contains.

Magnesian Limestone and St. Bees Sandstone. Neither of these formations, so far as can be seen, has any bearing on the subject, so that it will be unnecessary to describe them.

Superficial Deposits. The chief point of interest presented by these beds, as affecting the subject under consideration, is, that they frequently rest directly upon the deposits of hæmatite. They also contain a number of fragments and

boulders of hæmatite among the numerous rocks that compose their gravels and boulder clays, some of which fragments are polished and striated. Their thickness in some places in the Whitehaven area exceeds 140 feet, but in Furness they have been proved as much as 537 feet. Associated with this formation in Furness is a curious brecciated limestone locally known as "Crab-rock," and which was supposed by Murchison and Harkness to belong to the Permians, and to be the equivalent of the Eden Valley "Bockram."

Before closing this notice it may be profitable to glance for a few moments at some of the more salient points in the geological history of these districts. It will be seen, first of all, that, after the long period of deposition in which the vast mass of Silurians was thrown down, there succeeded a period of upheaval and severe denudation, in which those rocks were much dislocated and inclined, and a great part of them removed. Then came a submergence, and the putting on of the carboniferous rocks over the edges of the tilted and eroded Silurians. Layer after layer of these rocks were deposited until the huge pile included the limestone, the grits, and the productive coal-measures.

A second period of elevation and denudation then set in, and the newly formed carboniferous strata were fractured, uplifted, and inclined. At once meteoric and other kindred agencies commenced on them their work of destruction, which was continued, without interruption, until the quickly disappearing rocks were again submerged. The Whitehaven Sandstone was then spread out over their eroded edges, and the long-continued carboniferous era thus brought to a close. In a short time another upward movement was effected, this sandstone was eroded, and after a time sunk into the Permian Sea, where it was unconformably covered by the Permians. Another rise then took place, the rocks reared their heads from out of the "irony waters," and there they stood thence onward to "the great ice age," subjecting themselves to a continuous attack of those meteoric forces, by which they have been slowly moulded to their present form.

POSITION, FORM, AND INNER NATURE OF THE ORE DEPOSITS.

Deposits in the Eskdale Granite and Ennerdale Syenite. These are somewhat numerous, but so far as proved not of any great importance commercially. The principal deposits hitherto worked are in the granite. One of these is near Boot, in Eskdale. Another, but much smaller, deposit was worked near the "King of Prussia," in the same valley. Several similar veins have also been worked in a small way in the syenite of Ennerdale, notably at Crag Fell. They are all very much alike, both in form and inner nature, so that Nab Ghyll vein at Boot, which has been most worked, may be taken as typical. The form of this deposit is that of a vein. Its direction is nearly north and south, and it "hades" to the east at angles varying from 65° to 80° with the horizon.

In that part of it which, so far as is known, is most fully developed, its existence is indicated on the surface by a small ravine, known as Nab Ghyll, which runs down the southern side of the mountain that lies between Eskdale and the upper part of Miterdale. The ore is worked by levels driven into the hill at various heights. It is not continuous throughout the vein, but, as in most mineral veins, occurs in lenticular forms called "bunches" or "bellies." These bunches are usually thickest near their centre, whence they thin off, or as the miners express it "nip out," gradually towards the edges. Between the bunches there is invariably a "leader," marking the vein, but it contains very little ore; sometimes, in fact, none at all, being merely a strong joint. The length of vein that has been worked up to the present time is about 200 fathoms, and the depth to which the ore has been found to extend below the surface is about 50 fathoms. The greatest width of the vein has been about 20 feet, including 11 feet of "horse" or "rider." This was near the surface. Further down it is much narrower, and appears to die out altogether at a

depth of 50 fathoms. It is, in fact, a "gash" vein. A section of it at the surface, as seen in No. 1 Quarry, is shown in Fig. 1.

It will be observed that the vein, at this point, consists of four distinct lots of ore, separated from one another by three ribs of "horse" or "rider." The "hade" of the ore, as well as its "direction" horizontally, agrees exactly with that of the large joints (*d*) intersecting the granite. These joints are very strong and persistent, and give the granite at a distance the appearance of bedded rocks standing on end. The beau-

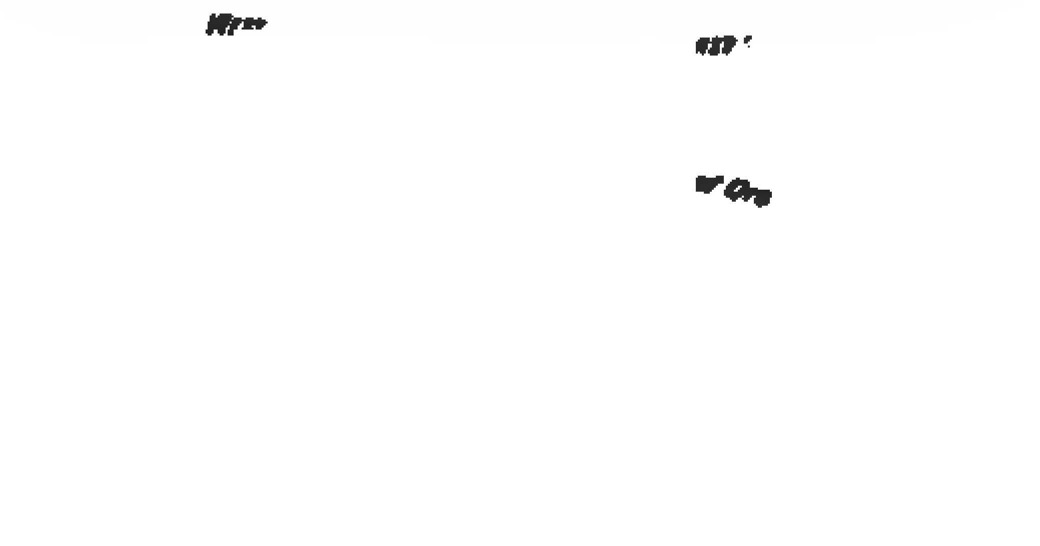


FIG. 1.—SECTION OF NAB GHYLL VEIN. (Scale 32 feet to an inch.)

References—*a* Boulder Drift. *b* Granite, decomposed adjoining the Ore. *c* Hæmatite, etc. *c'* Kidney Ore. *d* Joints in the Granite.

tiful ravine, on the opposite side of the valley, called Stanley Ghyll, seems to have been cut out along these joints. Frequently, from the main line of ore, small strings of it are found branching out into the granite along some of the minor joints by which this, in common with other granites, is also intersected. If two of these strings cross one another a small bunch is formed.

Near the surface the "cheeks" of the vein are very much decomposed, being most so adjoining the ore, whence the granite becomes harder and harder, until at a distance of a foot or two from the vein it assumes its normal condition.

The same thing occurs in the lower parts of the vein, only the amount of decomposition and the distance to which it extends into the cheek becomes less and less in depth. It is also observable that the cheeks are more decomposed where the vein contains ore than where it is barren.

Those parts of the vein marked *c* in Fig. 1 are not solid masses of hæmatite, but a mixture of red earthy-looking ore, hard fibrous kidney of purplish tint, black oxide of manganese, reddish clay, grains of quartz, similar to those in the granite, and pieces of more or less decomposed granite. Generally these various materials are arranged in broken lines parallel to the sides of the lode, as shown at *c*." Some of the more earthy-looking ore contains pieces of decomposed felspar, and it is sometimes possible to obtain a piece from the vein showing, on the one hand, hard pure kidney, and on the other granite very little altered—that is to say, there seems to be, in such a case, a gradual transition from granite to pure hæmatite. Some pieces of ore have been obtained from this mine having the appearance of "ring-ore." They are usually less than an inch in diameter, and in cross section present a number of concentric rings somewhat like the annual layers of an exogenous tree. Down the centre there is frequently a hole, as if the substance around which they seem to have been formed had disappeared.

Sometimes the ore is stalactitic, occurring then in cavities, and occasionally a piece of ore is met with united to dolomite in such a way that the two seem "grown together." The occurrence of dolomite in some of the veins in Eskdale is very common, and the author is of opinion that it has a most important bearing on the origin of these deposits.

The chemical composition of the ore from these veins is partly represented by the following analyses of ore from Nab Ghyll vein :—

	No. 1. Dried at 212° Fahr.	No. 2.
Ferric oxide	27·43	92·57
Manganous oxide	·03	·02
Silica	2·15	2·05

	No. 1. Dried at 212° Fahr.	No. 2.
Alumina	6·10	·88
Lime	23·18	·50
Magnesia	9·04	·08
Phosphoric acid	·04	·03
Sulphuric acid	·02	·01
Carbonic acid and water ...	32·00	3·70
	99·99	99·84
Metallic iron	19·20	64·80

No. 1 is much worse, and No. 2 better, than the average. No. 1 clearly contains a considerable proportion of dolomite.

Deposits in the Skiddaw Slate. At one place only has hæmatite been worked successfully in these rocks; that is at Kelton Fell and Knockmurton, two adjoining properties on one of the hills near Ennerdale Lake, in the north-east part of the district. The ore there occurs in the forms of veins as at Eskdale, but in two sets, one running about 37° north-west and south-east, and the other about 15° north-east and south-west. Seven separate principal veins have been more or less worked, five of which have the former direction and two the latter. They all "hade" towards the east at angles varying from 45° to 80° with the horizon. The greatest length that has been worked on any of them is about 240 fathoms, and the greatest depth 56 fathoms.

The ore is not continuous, but occurs in irregular detached lenticular masses or "bunches," as at Eskdale. These masses are thickest near their centre, having been known at Kelton No. 1 vein to be as much as 23 feet, but in this there was about 9 or 10 feet of "rider." Usually they vary from 2 to 10 feet, and thin off gradually from the centre to their extremities. Exceptions to this are occasionally met with, and the ore terminates very abruptly, as shown in Fig. 2, which is a vertical section through the lower part of one of these bunches in No. 1 vein, Knockmurton. Some of the bunches are over 50 fathoms in length. Between them the vein is nearly barren, sometimes, in fact, quite so, there being only a strong joint or two to mark its existence.

It has been seen that at Eskdale the vein is widest at the surface, becoming gradually narrower as it goes further down. Here it is so, too, in some cases, but in others the greatest width of the veins appears to be at some fathoms below the surface.

From what has been previously said respecting the joints traversing the Skiddaw slates, and more recently as to the

FIG. 2.—SECTION OF PART OF NO. 1 VEIN, KNOCKMURTON. (Scale 8 feet to an inch.)

References—*a* Skiddaw Slate. *b* Hæmatite. *j* Bed Joints.

bearing of these veins, it appears that the two are exactly parallel both in direction and "hade." In the mine this may be often very well observed directly, especially where there is a narrow string of ore occurring interruptedly, for it can then be seen most distinctly that the ore actually occurs in these joints, which by some means have been enlarged. This correspondence may also be seen in any of the small strings which branch out from the sides of the main veins. It

was previously stated that one or other of the two sets of joints sometimes coincides with the dip and strike of the strata. When that is so, and ore occurs along the joints, the deposit has a bed-like form, being, in fact, a "bedded vein."

At and near the surface the "cheeks" of the vein are very much altered from the normal condition of such rocks, being softer and more broken up; but as they get deeper they become harder and less altered. They are, moreover, less changed in those parts of the vein which are barren than in the productive parts.

The ore is, as a rule, much less mixed with extraneous matter than that of the veins in the granite. Like them, however, everything, be it ore or not, is arranged in lines parallel to the "cheeks." Usually a layer of hard kidney-ore is found running along both cheeks in concretions about an inch or two thick, the central part of the vein being filled with softer ore. Along the cheeks of some of the narrower veins, and near the surface, "combed" white quartz is met with. Some of the ore, in the centre of the veins, is broken kidney, which is quite tender, and lies in the most confused manner among ore of an earthy nature. Pieces of broken kidney-ore are also met with embedded in "brown spar." It appears then to occupy what was originally a "lough."

Most of the kidney ore on the "cheeks" has the convex side of the concretions turned towards the vein, but sometimes it is set in the opposite direction and faces the "cheek," seeming then as if the different layers had been put on from the centre outwards. In some of the wider veins layers of hard massive ore occur. They are parallel to the "cheeks," and in some cases three or four feet wide, the remainder of the vein being soft ore, as above described. "Loughs" are frequently met with in the ore. The sides of these loughs are composed of kidney-ore, and they often contain a quantity of minute crystals of quartz, some of which are coloured red by peroxide of iron. Here, too, as at Eskdale, some of the ore assumes the ring form, in other parts it is quite soft and micaceous.

One other feature of these veins remains to be noticed, and that is the occurrence in them of ribs of "rider" and small pieces of slate. The "rider" or "riders" (for sometimes there are more than one) are of the country rock, much decomposed, and have the same "hade" as the vein. The small pieces of slate lie scattered here and there through the ore. Some of them are very much decomposed, others are so deeply impregnated with peroxide of iron as to be almost indistinguishable from the more earthy ore in which they lie, whilst some appear to be very little altered. The way in which the smallest of these fragments are occasionally embedded in the ore give it, at a distance, the appearance of a porphyritic rock.

The tender nature of the "cheeks" renders it somewhat difficult to keep the ore clean, otherwise it is of excellent quality, as shown by the following analysis:—

Peroxide of iron	89·21
Siliceous matter	7·07
Water and carbonic acid	2·53
Lime, alumina, etc.	1·19
Total	100·00
Metallic iron	62·45

This was, in all probability, a picked specimen free from mechanical impurities. The following are nearer the average composition, although No. 2 is rather low in iron and high in silica, etc.

	No. 1. Dried at 212° Fahr.	No. 2.
Ferric oxide	80·22	69·14
Manganous oxide	·04	·06
Silica	13·10	18·44
Alumina	3·86	6·08
Lime	1·64	·88
Magnesia	·03	—
Phosphoric acid	·03	·05
Sulphur	traces	·03
Carbonic acid and water ...	1·20	5·20
Total	100·12	99·88
Metallic iron	56·15	48·40

The raw ore contains—

	No. 1.
Moisture	3·77
Metallic iron	54·03

Deposits in the Coniston Limestone. In this formation also hæmatite has been found only at one place, in such quantity as to induce any one to work it—that is, at Water Blean, near Millom, in the southern part of the district. Much of the ore obtained from this place has been used as a pigment, owing to its high red colour; but a considerable quantity of it has also been converted into iron. The principal part of this paint-ore was obtained from a cavity in the limestone immediately below the boulder drift. This is shown in Figs. 3, 4, 5, and 6. That part of the cavity which is bounded by a full line was merely a dish-like hollow in the limestone, so that the ore was lying just under the boulder drift. The part shown in dotted lines had a cavernous form, and between the overlying drift and the ore there was a roof of limestone. This will be further explained by reference to the sections which are taken along the lines A B (Fig. 4) and C D (Fig. 5) respectively. It will be noticed that some portions of the cavity have a north-west and south-east direction, whilst others have a north-east and south-west course. These two directions it will be further noticed correspond with the two sets of joints a'' and a''' (Fig. 3), by which the limestone is intersected. Their average bearing may be taken at 50° north-west and south-east, and 40° north-east and south-west.

Besides the ore obtained from these cavities, one or two short vein-like deposits have been worked which extend to a much greater depth. The greatest length yet proved on any of these is 17 fathoms, at one part of which the ore has been worked from the surface to a depth of 13 fathoms without reaching the bottom. As in the veins in the granite and Skiddaw slate, the ore here is not continuous, but occurs in short "bellies" somewhat like "pipes" or "chimneys." The greatest width yet met with in these deeper deposits has been about 14 feet. This was at the surface; 13 fathoms

below, the width was only 6 feet. Between the "bellies" of ore in the deposit that has been most worked, the only

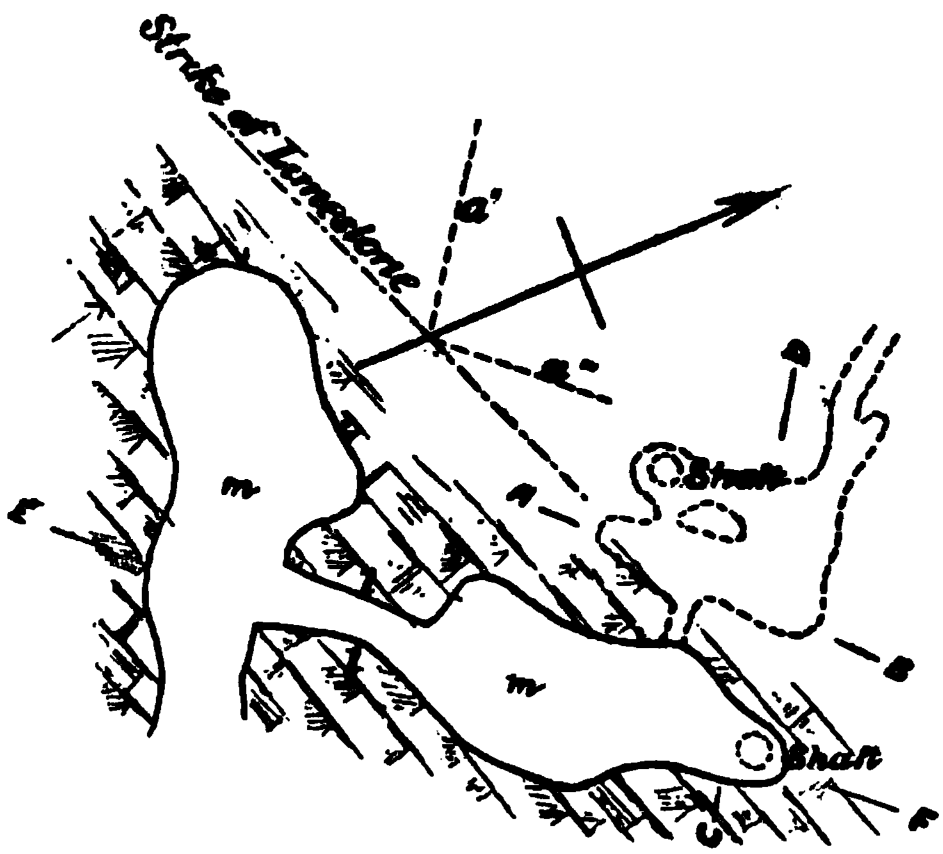


FIG. 3.

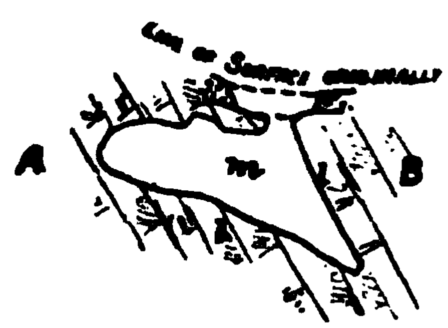


FIG. 4.

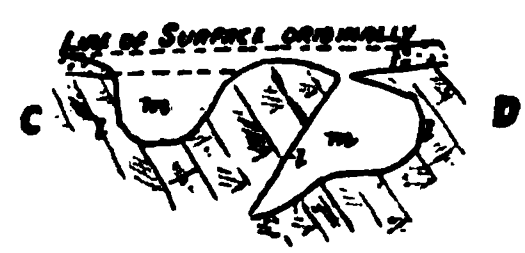


FIG. 5.

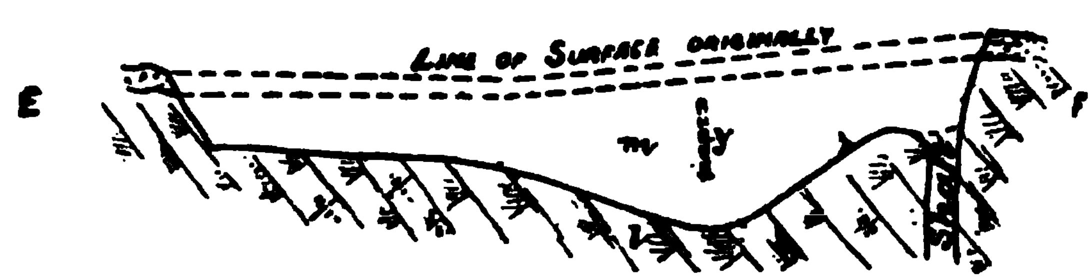


FIG. 6.

FIGS. 3-6.—PLAN AND SECTIONS OF WATER-BLEAN DEPOSITS. (Scale 60 Feet to an Inch.)

References—*a' a''* Direction of Joints intersecting the Limestone. *l* Limestone. *m* Cavity from which Ore has been removed.

indication of a vein is a strongly marked joint which forms a continuation of the lying "cheek" of the "bellies." The "nipping out" of the ore, and the consequent formation of

bellies, results from a closing in of the hanging side upon this joint, which maintains an undeviating course. The direction of these vein-like deposts is the same as that of the joints, which bear 50° north-west and south-east. The "hade" is likewise the same in both, being to the north-east.

The ore is not much mixed with the "country" rock or any other foreign substance. That from the vein-like deposits, especially in the deeper parts and against the hanging side, is generally very hard and of a bluish iron-grey, often peculiarly marked by dark glistening spots. The ore adjoining the lying "cheek" and in the top parts generally of the vein-like deposits, as well as in the shallow deposit shown in Figs. 3, 4, 5, and 6, is quite different, being much softer and of a reddish colour. This is what is used for paint ore. The composition of the harder ore is as follows:—

Peroxide of iron	65·31
Protoxide do.	7·60
Silica	7·96
Alumina	7·93
Lime	1·62
Moisture	2·28
Carbonic acid	7·30
Total	100·00
Metallic iron	51·63

The specific gravity of the softer ore is about 3·95.

When the ore comes in contact with the limestone there is sometimes a well-defined line of junction in the form of a joint, on one side of which there is limestone, and on the other ore. This is so on the lying side of the vein-like deposits above described, and at *l* and *l*." In other cases the ore and stone seem "grown together" and are inseparable, there being a regular gradation from one to the other.

In the softer ore some very curious structures occur, which have been supposed by some writers to be fossil plants. Mr. E. W. Binney, in a paper read before the Manchester Literary

and Philosophical Society in 1867, "On the Age of the Hæmatite Iron Deposits of Furness," speaks of having seen, in the possession of Miss Hodgson of Ulverston, remains of *Lepidodendra* and *Stigmaria* which were found in this deposit. Miss Hodgson, in a paper "On the Water Blean Iron Ore," published in the *Geological Magazine*, March 1870—prefacing her remarks by the statement that her information was received from the manager of the mines—says, that "in the early part of the year 1866 a large tree trunk was met with standing erect. It was from twelve to fifteen feet high, and from twenty to twenty-four inches in diameter at the base. As the miners came upon the tree at two levels" (Miss Hodgson continues) "I was anxious to learn whether any bark-markings had presented themselves; but while it was admitted that, roughly, there might have been been some resemblance to certain bark structures, yet it must mainly be described as having had a coarse sparry crust with vertical pipes running through it. . . .

"The above tree-like form was not the whole of the discovery; imbedded likewise in the ironstone and occurring, for the most part, near the walls of the place, and low down, were numerous twig-like remains. These are of a harder nature than the trunk mass—they are in better preservation—and in some specimens exhibit beautiful minute striation, with what seem to be little scars arranged in a uniform pattern."

The writer has in his possession a specimen of the tree trunk, and also a number of the twig-like remains, which he has examined very carefully. They are not all of the same shape, some of them having a crescent form in section, whilst others are approximately triangular or nearly round. So far as he is able to judge, these so-called fossil plants are nothing more than concentric pipes of kidney ore, between the successive layers of which there is a thin ring formed by crystals of calcite; in fact, they seem to be but a particular case of "ring ore" structure, the so-called tree trunk being formed by a mass of these small structures in contact. The

outermost ring is frequently marked by irregular flutings, but these markings may also be found in other parts of the ore apart from the twig-like remains. The specimens in the possession of the writer do not, so far as he has seen, exhibit "the uniform pattern" alluded to by Miss Hodgson, and the only approach to it is the interior and exterior faces of the minute mammillations of the rings of kidney ore. At first sight, these certainly do present some resemblance to the markings of *Lepidodendra* and *Stigmaria*, but whether they are the characters upon whch Mr. Binney based his generic determinations cannot be said.

Laminated barite, crystals of quartz, and "black muck,"—which consists of varying proportions of silicious and aluminous materials, and of the oxide of iron and peroxide of manganese—are sometimes associated with the ore of these deposits.

Deposits in the Carboniferous Limestone. These are the most important deposits in the district. They are both large and numerous, very varied in form, and present a number of interesting features, which are not met with in any of the deposits previously described. As already stated, they occur in all the main beds of limestone. In the Whitehaven district they are most numerous in the Langhorn, Clints and bottom beds, in one or other of which all the largest deposits in the district are found. Their form is variable, being sometimes *bed-like*, sometimes *vein-like*, at others filling *dish-like* hollows in the limestone, immediately below the drift, whilst not unfrequently—but chiefly in the Clints limestone—they have a most irregular shape, and are at some depth in the limestone, by which, and its associated rocks, they are in most cases entirely surrounded. The bed-like deposits are peculiar to the Whitehaven district. So far as the Author is aware, there is not a single deposit of this description in Furness, unless the small "flats" from the Lindal Moor and Stank veins be considered such.

This absence of "bed-like" deposits in Furness is curious, and evidently arises from the fact that the limestone occurs

almost in one solid mass, and is not separated by intervening layers of sandstone and shale into beds, as at Whitehaven. The rocks in Furness forming the carboniferous limestone series being everywhere of the same character, there is nothing which could induce a bed-like form of deposit.

The Bed-like Deposits occur mostly in the first, second, and bottom limestones of the Whitehaven district; in fact, the deposits in those beds assume this form exclusively; but the bed-like form is not confined to these horizons, for it is also met with in the third, fourth, fifth, and sixth beds of limestone. As already stated, the first limestone is overlaid by the millstone-grit series, the lowest bed of which is of an arenaceous nature.

FIG. 7.—SECTION OF PARKSIDE DEPOSIT. (Scale 405 Feet to an Inch.)

References—*A* Boulder Clay. *B* Sandstone, *C* Shale (Millstone Grit). *D* Limestone, *E* Sandstone, *F* Shale (Yoredale Rocks). *G* Hæmatite.

Under the limestone is a thin sandstone bed, usually called whirlstone, and then a bed of shale. In the Bigrigg locality these two beds are known as the "little whirlstone" and the "little sill" respectively. It is seldom that the ore occupies the whole thickness of the first limestone, being mostly confined either to the top or bottom of it. At Frizington and Winder Gill it occurs mainly in the top, as shown in Fig. 7, which is a vertical section of part of the large deposit worked by the Parkside, Crossgill, and (part of) the Highhouse mines. The "roof" of the ore is the bottom bed of the grit series, which has the same regular dip as the rest of the strata. The "sole" is partly sandstone; the greater portion of it, looking

at the section, might be expected to be limestone, but it is not, being mostly silica, and called by the miners "whirlstone." A very remarkable feature of the limestone of this district, and one which seems scarcely ever to have been noticed, is that any bed of it at one place may be a pure limestone, whilst at another and not far distant place the same bed may be the hardest whirlstone.[1] A recognition of this fact removes one of the greatest difficulties there is in the way of correlating the various sections that have been obtained in the different parts of the district. But to revert to Fig. 7. Unlike the roof, the "sole" is generally very uneven, being, in places, like a number of waves. These waves the miners call "rolls." Some of them are of great length, and they all run about north and south; the ends of them only are seen in Fig. 7, as the plane on which the section is taken cuts them at right angles. On the top of the "rolls" the ore is thinnest, being sometimes only a few inches, at others it is as much as twenty feet. In the hollows between the "rolls" the ore is of course thickest, being fully forty feet in some places. The sole has not this waved appearance everywhere; for when the ore occupies the full thickness of the limestone bed it runs parallel to the roof. Sometimes the ore is seen to run up into the grit roof in narrow strings, from an inch or two to a foot or more wide, and sometimes it extends from these strings for a little way along the bed joints. All the strings have a north and south direction. The length of the deposit on a north and south line is about 450 yards, and its breadth from east to west is about 370 yards. Its area is about 34 acres, so far as worked, being larger in superficial extent than any other deposit in the district. It has also yielded the largest quantity of ore. Its direction is nearly north and south. The tongues of ore extending from the north end of the main body have also this direction, which is the same as that of the "rolls" in the floor and the "strings" in the roof, the whole of them being parallel to the north and

[1] This word is very loosely used in the district, being applied sometimes to hard sandstone, at others to grits, or, as above, to the silicious portion of the limestones.

south joints intersecting the limestone. As shown in the section, the ore dips to the west, and on its eastern side occurs just below the drift, but further westward, that is, to the dip, the grits are over it; and by the time the western side of the deposit is reached it is overlaid by about sixty fathoms of these rocks.

At Bigrigg the ore is found in the first limestone, at the bottom of the post, as shown in Fig. 8, which is a cross section of part of the large deposit worked by the Fletcher pit, Sir

FIG. 8.—SECTION OF FLETCHER-PIT DEPOSITS. (Scale 32 Fathoms to an Inch.)

References—*a* Boulder Clay. *b* Shale (Permian). *b'* Millstone Grit, *b''* Little Sill. *c* Breccia (Permian). *d* Sandstone or Grit. *d'* Little Whirlstone. *e* Hæmatite. *f* Grit. *g* 1st Limestone. *g'* 2nd Limestone.

John Walsh pit, Robin Benn pit, etc. Here, in many points, a state of things is found exactly opposite to that which prevails at Frizington. There the roof is even and the floor uneven; here it is the floor that is even, whilst the roof is generally very irregular indeed. The little whirlstone forms the floor, and the roof consists chiefly of silicious portions of the upper part of the first limestone. Owing to the irregularity of the roof the thickness of the ore is very variable, being sometimes over thirty feet, and at others less than a foot.

This great variation results mainly from the ore assuming at times certain vein-like extensions upwards, called by the miners "guts." These guts are shown at *h* Fig. 8. They vary in width from a few inches to five or six feet or more, and sometimes they open out under the basement bed of the grits or along one of the bed joints, and form a minor deposit along the top or near the middle of the limestone. The "guts" are all nearly parallel, and run about north and south. The length of the whole deposit is about 550 yards, and its average breadth about 200 yards. The ore does not lie in a compact body as at Parkside, but is split up by elongated masses of limestone into parts which bear nearly north and south. On the western side of the deposit these rock masses increase to such an extent as compared with the ore, that the latter is only a network of "guts" or veins, but their direction is parallel to that of the larger masses, both being, in fact, parallel to the north and south joints intersecting the limestone. The dip is to the west, and, as at Parkside, the ore, in places, at its rise edge, occurs immediately below the drift, but soon becomes covered, dipward, by Grits and Permians, as shown in Fig. 8. At James pit, on the west side of the deposit, the thickness of these overlying rocks is about sixty-four fathoms.

Besides these deposits there are several others in the first limestone, but they are all, more or less, similar to those described, so that it is not necessary to speak of them separately. In the second limestone the deposits have also a bed-like form. They chiefly follow the sole, and have an irregular "roof" and regular "sole," as shown in Fig. 8.

The writer is not aware that this form of deposit has been met with in the Clints limestone, but a good example of it in the fifth limestone was worked in No. 7 pit, Eskett Park. From the high angle at which this deposit dipped it was generally spoken of as a vein, the miners working it using the terms "hanging cheek" and "lying cheek," for what were in reality the "roof" and the "sole" respectively. On the south-

east the ore is cut off by a large north and south upthrow fault, which brings the Skiddaw slate to the surface. The throw of this fault at the Agnes pit, a little to the north, is about 190 fathoms, the Skiddaw slate and St. Bees sandstone being in contact. Where the ore abuts against this fault it is very thin, but it becomes thicker to the dip. The "roof" is usually formed by a bed of shale, and so is a great part of the "sole," but sometimes irregular masses of silicious stone are found intervening; so that for a time the "roof or "sole," or both, may be stone.

Bed-like deposits also occur in the sixth and bottom limestones. The best examples in the latter bed are to be found in the Woodend and Egremont districts. There the ore occurs mostly on the shale underlying the bottom limestone, although in some cases there is an intervening layer of silicious limestone. The roof invariably is limestone, and generally very irregular, causing great variations in the thickness of the ore.

Where a bed-like deposit occurs between two beds of shale, or of shale and sandstone, and the upper layer, in places, forms the roof of the ore, whilst at other points there is an intervening layer of limestone, it is found that the vertical distance between the shale, or shale and sandstone, beds is less when the ground between them is all ore, than when it is partly ore and partly limestone. This may be the result of the upper shale or sandstone having sunk a little during the deposition of the ore, or it may be that the original limestone was thinner there.

Vein-like Deposits. Perhaps the best example in the Whitehaven district of a deposit of this form is that worked at the Salter Hall mines and Postlethwaite's Eskett mines. It is on the line of a large north and south fault, having an upthrow to the west, at the latter mine, of about 120 fathoms. The deposit is in the third and Clints limestones, and at its south end is very shallow, being overlaid only by the drift; but having the same dip as the strata, that is to the north-west. It gets deeper as it goes northward. At that end it

becomes most vein-like. A section of it at the north end of the Salter Hall mines is given in Fig. 9. The ore, it will be noticed, is narrow for some distance down, to *l*; it then widens considerably, and the "hanging cheek" changes its character.

Above this point it is very silicious, but here the rocks contain a large proportion of lime. On the upside of the fault

FIG. 9.—SECTION OF SALTER-HALL DEPOSITS. (Scale 180 Feet to an Inch.)

References—*a* Superficial Deposit. b^1, b^2, b^3, b^4, b^5, b^6, and b^7—1st, 2nd, 3rd, 4th, 5th, 6th and 7th Limestones respectively. *c* Shale. *d* Sandstone. *e* Hæmatite. *f* Skiddaw Slate.

there is Skiddaw slate for about one-third the depth of the section, the remainder being "whirlstone," limestone and shale, intercalated with which are two bed-like extensions of ore, called by the miners "flats" or "flat-ore," the uppermost being in the fifth, and the lower in the sixth limestone. There is thus the fact of a deposit of ore—for really the whole of the ore, both bed-like and vein-like, may be looked upon as one deposit only—being partly in the third, fourth, fifth, and

sixth limestones. The ore frequently formed "flats" on the downside of the fault, as well as on the upside.

Another large vein-like deposit is found by the side of the north and south fault running through by Agnes pit and Yeathouse pits. Its character throughout is very similar to that just described, but at Agnes pit the "flats" occur only in the hanging or down side; the upside of the fault consisting entirely of Skiddaw slate. On the contrary, the "flats" at Yeathouse mines are wholly in the upside, the hanging cheek being breccia and St. Bees sandstone.

At Birks there is another vein-like deposit, which is also on the line of a north and south fault. There, too, as at Yeathouse, the "flats" are in the upside, the downside being St. Bees sandstone and breccia.

A feature of the vein-like deposits of the Whitehaven district, worthy of mention, is that they all "hade" towards the east, like the veins in the granite and Skiddaw slate, the amount of "hade" being usually about 50° with the horizon.

Some of the most important deposits in Furness are also of this form—those at Lindal Moor being the finest. The length of the principal deposit there, so far as worked, is about 1,000 yards, in a direction about north 25° west, and south 25° east. Its breadth is very variable, sometimes being only a few inches wide, whilst at other places it is over 30 yards. Fig. 10 is a section across the northern end of the vein at a point where the width was more regular.

From that section it will be seen that the deposit is laid alongside a fault—in fact, three faults are seen; but whether they continue alongside the deposit from north to south cannot be said, as the "lying cheek" or foot-wall, as the rocks on the upside of the fault are called, have not been sufficiently laid open at the southern end of the deposit; but the ore at that end of it lies on the most westerly of the three faults shown in the above section. The footwall of the vein is very regular, as shown in the section, and the varying width of the ore just noticed is entirely due to the irregular form of the "hanging wall," as the rocks are called, on that side of the

vein opposite the "footwall." At the northern end of the vein the ore has been worked to a depth of nearly 60 fathoms, and the bottom of it has been reached. In the southern end it is now being worked at 70 fathoms, and ore is still going down in the sole of the lowest workings.

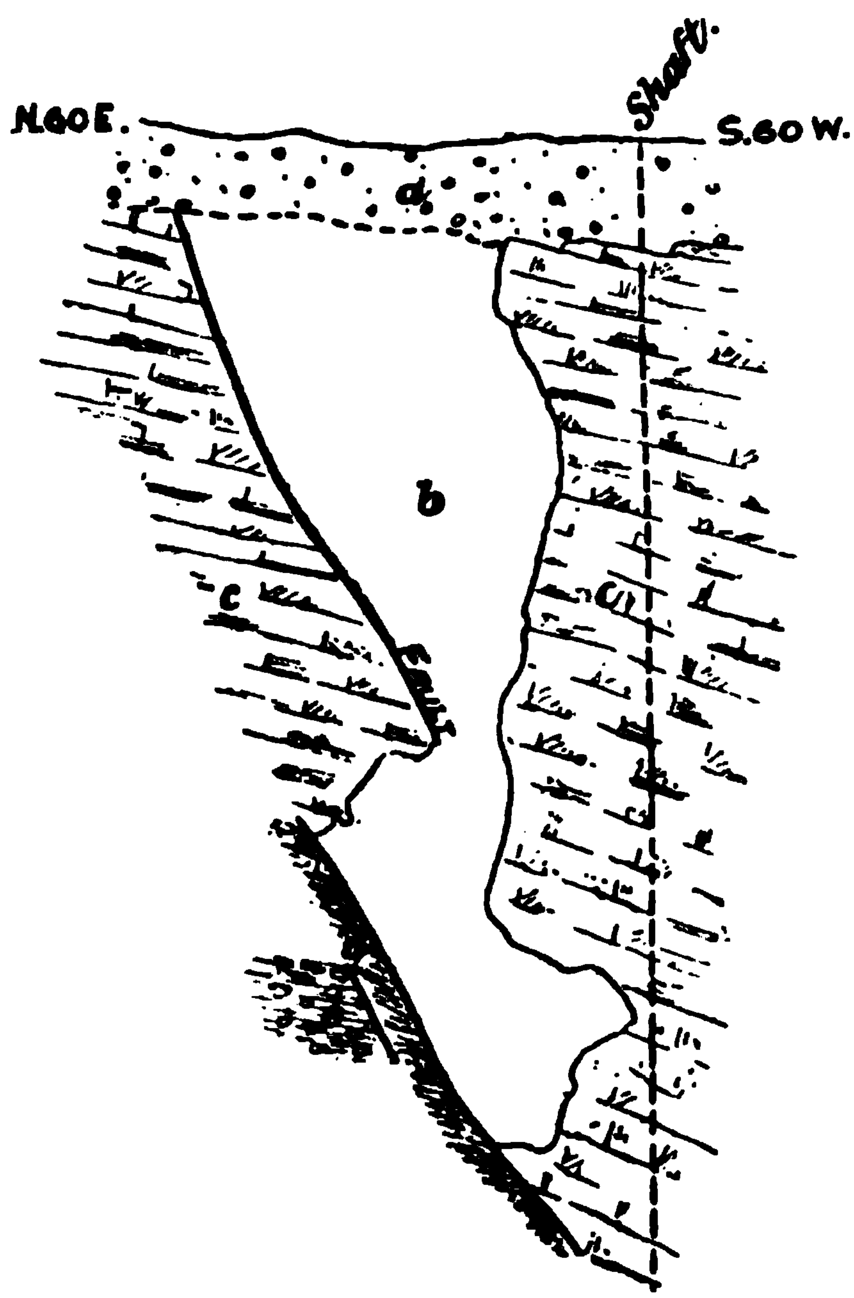


FIG. 10.—SECTION OF LINDAL-MOOR DEPOSIT. (Scale 120 feet to an inch.)

References—*a* Boulder Clay. *b* Hæmatite. *c* Carboniferous Limestone. *d* Limestones and Shales. *e* Conglomerate.

Another vein-like deposit of some importance in Furness is being worked by the Stank mines, and by some of the pits of the Yarlside Mining Company. This deposit was found by the Barrow Steel Company when they were searching for coal in the Yoredale rocks, near Stank. Here, too, the ore occurs by the side of a fault; but in this case it is in the rocks on the

upside, whereas at Lindal Moor it is on the downside of the fault. Near the upper part of the vein there is a "flat" of ore, but so far as yet proved it is not of great extent. This "flat" is the only approach to a bed-like deposit, in Furness, that has come under the writer's notice, and the only one, so far as he knows, that has been found there.

The direction of the vein is about 25° north-west and south-east. It has been worked for a length of about 600 yards, and for a depth of about 30 yards, without reaching the bottom. The width varies from a few inches to about 25 yards, including the masses of limestone which are embedded in the ore. Occasionally these limestone masses are so large, and so elongated in the direction of the vein, that the ore is, in places, split up into a number of vein-like bodies which are parallel to one another, in the main, but being of irregular breadth, communicate at intervals, and form a sort of network of ore in the limestone. The "hanging" wall is quite regular, and the variations in the width of the vein are due to the irregular form of the "lying cheek."

This is just the opposite of what is seen at Lindal Moor, but the two deposits correspond in this, that the regular side of the vein in each case is that on which the fault is situated. The limestone at Stank is overlaid by Yoredale shales, which dip in a south-easterly direction, that is, along the course of the vein. The ore is confined entirely to the limestone, and does not go up into the shales, so that the vein may be said to have a dip south-eastward, corresponding to that of the surrounding strata. It has thus two dips—one westward, due to the inclination of the fault by the side of which it is laid, the other south-eastward, like the adjoining limestone.

This longitudinal dip of the ore and the accompanying increase in the thickness of the overlying shales are such, that at the most southerly point worked the upper part of the vein is at a depth of about 80 fathoms from the surface, whilst near the Yarlside mines the same ore is reached at a depth of

about 40 fathoms. The vein seems to be best at the rise end, and to become smaller as it is followed in below the shales. This feature is often seen in similar deposits in the Whitehaven district.

Another vein-like deposit occurs at Yarlside Mines. Its direction is about north-east and south-west, corresponding with that of the fault along which it is laid. Ore has been worked here to a depth of 42 fathoms from the surface without reaching the bottom. As in the two deposits just described, its width is exceedingly variable. Sometimes the ore is found close against the fault, at another time there is a piece of silicious stone between them.

In the vein-like deposits, hitherto found, notwithstanding the great variations in their width, there is a general narrowing downwards.

All the vein-like deposits of Furness are in what may be called the eastern side of the district, or on the east side of the great north and south fault which runs through by Parkhouse and Dalton; and it is curious to observe that all the deposits above noticed have a westerly "hade," that is to say, the faults along which they lie are down to the west. This is just the opposite of what is found in the Whitehaven District. There the north and south faults are mostly up to the west. But in that district the rocks have a westerly dip, whilst in Furness, at least where the vein-like deposits have been found, they dip south-east.

Dish-like Deposits are not numerous in West Cumberland, nor, with one exception, are they important. The exception is the larger deposit at Hodbarrow. It occurs in the equivalent of the thick limestone of Furness. Its extent has not been fully ascertained. Its length, so far as known, is about 1,000 yards, and its breadth 400 yards; its greatest thickness is about 130 feet, and the average perhaps 65 feet. The deposit contains very little stone or other foreign matter, so that it may almost be looked upon as a solid mass of ore. It is one of the largest deposits in West Cumberland, and the only one of its kind of any importance in that district. In

Furness, however, they are very common; in fact, most of the large deposits there have a dish-like form. It is overlaid only by sand, gravel, and clay, of the drift period, whilst below and around it is one mass of limestone. Its direction is nearly north and south, and corresponds exactly with that of the main joints in the limestone.

As just stated, most of the deposits in Furness are of this kind. In their simplest form they are roughly like filled irregular basins, just below the drift; but in some of the more complicated forms this resemblance is somewhat remote, owing to the fantastic outline of their sides. At other times deposits of this kind are so long, as compared with their breadth, that they seem almost like veins. Figs. 11 and 12 are plans of the Park deposit—the largest deposit of this or any other kind in the district. Fig. 11 shows the form of the deposit at 40 fathoms from the surface, and Fig. 12 its form at 50 fathoms. In an east and west direction the deposit measures about 360 yards, and in a north and south line its greatest length will be about 260 yards. The average thickness of the drift overlying the ore would be about 10 fathoms. The deposit has been worked down from that level to about 83 fathoms from the surface, and the bottom of it is not yet reached. These figures, it must be understood, give an extreme idea of the size of this deposit. Moreover, it contains large quantities of sand and clay to be hereafter noticed; but still it is an enormous mass of ore, and there is no deposit of the same kind in Furness which approaches it in size.

Branches of ore from these deposits frequently assume a vein-like form, which are called "ginnels." They are, however, different from the vein-like deposits above described. In the latter one cheek is *regular*, but in the former both cheeks are very *irregular*. Moreover, they do not *appear* to be laid along faults, but their direction corresponds nearly with the north and south joints in the limestone. Some deposits consist almost entirely of these "ginnels," as at Bolton Heads. Where such is the case they usually extend up to the drift.

Irregular-shaped Deposits. The best example of this form of deposit is probably that worked by Lord Leconfield's Wyndham and No 7 pits at Bigrigg. That deposit occurs in

Fig 11.—Plan at 40 fathoms level.

Fig. 12.—Plan at 50 fathoms level.

FIGS. 11, 12.—PLANS OF PARK DEPOSIT. (Scale 180 yards to an inch.)

References—*a* Carboniferous Limestone. *b* Hæmatite. *c* Sand. *d* Clay, etc.

the Clints limestone on the south side of an east and west fault, which throws up to the south about 19 fathoms, and cuts off the grits of Fletcher pit and James pit; at the same time,

bringing up the "little whirlstone" to the surface, and exposing it to view in the bottom of Langhorn quarry. A section of the deposit is shown in Fig. 13. On the north side of the fault are bed-like deposits in the first and second limestones, which were worked by Lord Leconfield's Nos. 5 and 6 pits.

The deposit under consideration is on the opposite side of the fault. When viewed in section, as in Fig. 13, its outline is most irregular, and so is its horizontal profile—tongues of

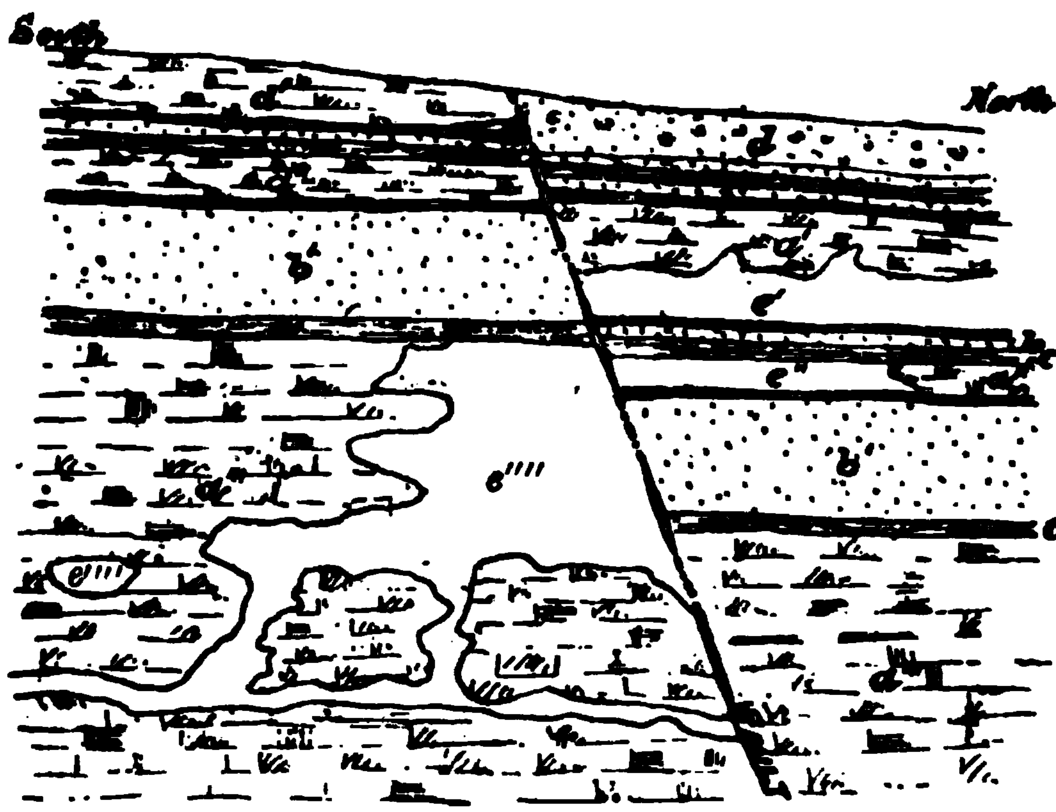


FIG. 13.—SECTION OF WYNDHAM PIT. (Scale 200 feet to an inch.)

References—*a' a'' a'''* 1st, 2nd and 4th, Limestones respectively. *b b'* Sandstone. *c c'* Shale. *d* Boulder Drift. *e' e'' e'''* Hæmatite in 1st, 2nd, and 4th Limestones respectively.

limestone of various lengths and breadths running into it in a north and south direction, and splitting it up in the most fantastic manner. Its greatest length is about 340 yards, its greatest breadth 208 yards, and its greatest thickness 200 feet. Owing, however, to the splitting up of the deposit by masses of limestone, its average dimensions probably do not equal half its greatest dimensions. The lower part of the deposit is somewhat bed-like, having the same dip and strike as the strata; and the ore connecting this with the main mass

above has a pipe-like form, its area in horizontal section being very small. The general direction of the deposit is north and south, and so is that of the several masses of ore into which the deposit is divided by the protruding tongues of limestone. The "roof" of part of the deposit is formed by a bed of shale; everywhere else it is enclosed by limestone or its silicious concomitant, "whirlstone."

Another very large deposit of the same kind, and in the same limestone, was worked at Montreal mines by Mr. Stirling. It occurred on the south side of a large east and west fault, which has a throw down to the north at that point of about 240 fathoms. Its length from north to south is about 220 yards, its breadth about 180 yards, and its average thickness about 45 feet. Other similar deposits occur in the same limestone in various parts of the district, but there is nothing about them which is peculiar as regards their form, so that they demand no special notice.

There has only been one good instance of this kind of deposit in Furness, and that was at Askam. There, the ore was entirely surrounded by limestone toward the dip; but, in another part of the deposit, on the rise the ore lay immediately below the surface in a dish-like hollow, somewhat similar to the deposit at Park. From the main body of the deposit numerous "ginnels" protruded like fingers from the hand, and the direction of these "ginnels" always corresponded with that of one or other of the main joints in the surrounding limestone—mostly with the joints running nearly north and south. The total area of the deposit, including the large masses of limestone that projected into the ore from the sides, roof, and sole, would be about 16 acres. Its length in a north and south direction would be about 260 yards, and from east to west it would be about 300 yards. It was overlaid by about 16 fathoms of drift, and on the dip side of the deposit, where it had a rock roof, the ore extended to a depth of about 40 fathoms. Generally, the deposit, notwithstanding its irregular form, had the same dip as the limestone. It therefore extended to a less depth on the rise where it came up to the drift

than on the dip side where it had a rock roof. This is a common feature of deposits, both in this district and at Whitehaven.

The particular *forms* of the deposits having been described, it is now proposed to glance at their more *general features*.

Inner Nature of the Deposits.

In the case of some of the deposits already spoken of, it was stated that they were split up by tongues of limestone or "whirlstone," in such a way that the bearing of the different parts of the deposit corresponds very nearly with the magnetic meridian. This may be said to be the case generally, unless the deposit occurs alongside an east and west fault. Then, it sometimes happens that the longer axis has an east and west direction. For instance, alongside the coal measure fault which runs in an east and west direction through the Montreal mines, there is a deposit of ore which extends from No. 2 pit, Montreal, to No. 2 pit, Crossfield, a distance of about 320 yards, whilst its greatest extension southwards from the fault is only 150 yards. It is, however, only in a case of this sort that a deposit is longer in an east and west direction than it is from north to south, and not always then, for the Wyndham pit deposit at Bigrigg is twice as long in a north and south direction as it is from east to west, yet it occurs by the side of an east and west fault.

Another feature of these deposits, as they occur in the Whitehaven district, is that they usually lie by the side of a fault, a fact the importance of which will be rendered more clear by an enumeration of the principal deposits so occurring. Every fault of any importance runs either in a north and south direction, or nearly at right angles to it, so that deposits in this connection may be divided into two sets—those by the side of north and south faults, and those by the side of faults having an east and west direction.

Deposits alongside North and South Faults. The

deposit worked by the Salter Hall mines, part of Eskett Park mines, Postlethwaite's Eskett mines, and the Winder Gill mines is partly on the up and partly on the down side of a fault which runs through by Winder Station.

Coming further west there is another fault at Yeathouse, by the side of which are deposits that have been worked by the Eskett mines, part of Eskett Park mines, part of the Winder mines, the Yeathouse mines, and the Lonsdale mines.

The next fault of any importance is at Birks, alongside which occurred a deposit worked for many years.

Coming down to Cleator there is a fault running through Jacktrees mines, Crossfield No. 10 pit, and Mr. Stirling's Nos. 9 and 6 pits. Then there is another by the Cleator Iron-ore Company's old opencast, the opencast and No. 7 and No. 8 pits Crossfield, and Mr. Stirling's No. 5 and No. 7 pits.

The deposits worked by the Cleator Glebe pit and the Cleator Iron-Company's ore No. 21 pit, are by the side of a fault having this direction.

At Bigrigg there is another fault, by the side of which is the deposit worked by the old pits of Lord Leconfield on Bigrigg, and the Meadow pit of Messrs. Lindow.

The Southam and Pallaflat deposits are both alongside north and south faults, and so are those worked by the Gillfoot Park and Wyndham Mining Companies.

Deposits alongside East and West Faults. By the side of a fault with this direction are Lord Leconfield's Bigrigg pits at present working, and some of the Woodend pits.

Along the fault already mentioned as passing through Montreal mines, are Dalzell's Moor Row pits; Mr. Stirling's pits numbered 1, 2, 3, 4, 6, 8, 10, 11, and 12; Crossfield No. 2 pit; and Lord Leconfield's James pit.

At Frizington a fault runs through the Highhouse pits numbered 1, 2, and 5, and between the Goosegreen and Scalelands pits.

Lastly, there is a fault with this direction running through

the Mowbray No. 2 pit shaft. Some of the pits along these lines of faulting are omitted, but the principal are included; from which it will be seen that all the most important deposits in the district are by the side of faults. It may also be observed that nearly all the north and south faults "hade" to the east, whilst those having a direction nearly at right angles to them "hade" to the north.

The throw of some of these faults is very large, and very often, in those having a north and south direction, the amount of throw increases toward the hills.

Faults are most difficult of detection in Furness for the reasons already stated, but several most important deposits are clearly by the sides of such dislocations. Among these may be mentioned the deposits at Lindal Moor, Pennington, Yarlside, and Stank.

Another feature of importance in these deposits is that they nearly all, at some place or other, rise out to the denuded surface of the tilted carboniferous rocks, and are there covered only by either Permian breccia or drift.

The ore of the Whitehaven District is chiefly of the hard, massive kind, although in some places it is much harder than in others. In colour it varies from a brownish-red or purple to a bluish iron-grey. Its composition is partly shown by the following analyses:—

	No. 1.
Peroxide of iron	98·26
Silica	1·59
Phosphate of iron	·30
Lime and magnesia	traces
Total	100·15
Metallic iron	68·78
Specific gravity	4·92

This was a piece of "kidney" from old Parkside mines. The general composition of a first-class ore is more like that

shown in No. 2 and No. 3, the first of which is an analysis of an average sample of the Southam ore, the latter of a sample from Hodbarrow :—

	No. 2.		No. 3.
Peroxide of iron	88·73	...	84·41
Protoxide of manganese	trace	...	·32
Silica	4·96	...	7·36
Alumina	1·94	...	·97
Lime	·41	...	·70
Magnesia	·12	...	·11
Baryta	·13	...	—
Carbonic acid	·44	...	1·09
Phosphoric „	·03	...	·03
Sulphuric „	·05	...	·01
Water	3·10	...	5·00
Total	99·91	...	100·00
Metallic iron	62·11	...	59·09
Specific gravity	4·5	...	—

The following analyses will convey some idea of the great variation there is in the quality of ore yielded by different mines :—

	No. 4. Dried at 212° Fahr.		No. 5.
Peroxide of iron	83·57	...	62·63
Protoxide of manganese	·18	...	·34
Silica	9·42	...	21·74
Alumina	1·25	...	·20
Lime	1·12	...	3·49
Magnesia	·19	...	·17
Phosphoric acid	·05	...	·02
Sulphur	·05	...	·04
Carbonic acid	2·10	...	2·74
Water	1·23	...	8·43
Total	99·16		99·80
Metallic iron	58·50	...	43·84
Moisture lost at 212° Fahr. ...	5·55	...	—
Specific gravity	—	...	3·32

No. 4 is an average of 78 samples of a good ore.

No. 5 is an average analysis of a very poor deposit of ore. The highest metallic yield in a large number of analyses of ore from this mine was 58·49 ; the lowest 21·72 per cent.

When any of these ores are examined under the microscope they are found to contain numerous minute cavities. In "kidney" and "pencil" ore these cavities are empty, or nearly so; but in the poorer ores they are entirely filled with silica. "Pencil" ore absorbs about $\frac{1}{220}$th of its weight of water; the silicious ore, yielding No. 5 analysis above, does not absorb any water.

Here and there in the ore are cavernous spaces called "loughs," which vary in shape from lenticular to spheroidal, and in size from a few inches to 3 or 4 feet or more across. The ore forming the walls of these loughs has invariably the kidney structure. It occurs in concretions round the loughs to a depth of several inches, the concretionary structure becoming less and less distinct outwards from the lough, and finally dying away into the massive ore around it. Some of these loughs are filled with brown spar, and sometimes the ore appears to be interlayered with it; at other times broken pieces of kidney are found lying pell mell in the spar. Embedded in the hard ore at Dalzell's Moor Row mines, the writer found, several years ago, some most remarkable structures of hæmatite. They resembled in form small door knobs, being perfectly even, smooth and shining on the surface. When broken they showed a radiating structure, the lines, which were curved, converging in the stem of the knob.

The ore of the Furness deposits may be divided into three classes:—

1. *Hard, compact, blue-purple ore*, in which there are numerous loughs, lined with kidney-like concretions and spar, such as occur in the Whitehaven deposits. This kind of ore is found in the northern end of the Lindal Moor deposit, in the Stank deposit, and in part of the Askam deposit. Its composition is as follows:—

	No. 1.	No. 2.	No. 3.
Ferric oxide	78·61	83·00	94·23
Protoxide of manganese ...	·24	—	·23
Silica	16·45	15·50	4·90
Alumina	1·87	—	·63
Lime	·56	trace	·05
Magnesia	·24	—	trace
Phosphoric acid	·03	—	trace
Sulphuric "	·04	—	·09
Water	2·02	1·50	·56
Total	100·06	100·00	100·69
Metallic iron	55·03	58·10	65·98
Specific gravity	4·34	4·53	4·83

Although the outward appearance of this hard ore suggests the idea that it is very compact, yet, on being submitted to the microscope, it is found to contain a number of minute cavities. These cavities are mostly filled with silica, and their proportion to the mass is about the same as that of the silica in the above analyses; so that the silicious quality of these ores in this district and in West Cumberland is, as indicated by chemical analysis, and still further demonstrated by micro scopic analysis, due to a mechanical admixture of quartz. The larger cavities in the ore that are visible to the unaided eye, and which are locally called "loughs"—also contain a quantity of silica in the form of quartz spar; but this does not much affect the analyses, as most of it is thrown aside in working the ore. The kidney ore, when seen under the microscope, contains very few cavities, and, as might be expected from that fact, its chemical analysis shows very little silica. The more silicious the ore the greater is the number of minute quartz-filled cavities which it contains. A few of the "loughs" are lined with calcite and specular ore, but, as stated above, they mostly contain quartz. Many of the "loughs" are filled with spar, others only partially so. The proportion of both filled and open "loughs" to the volume of ore will probably be about one-sixth. As in the Whitehaven deposits, the kidney ore is invariably found forming the walls of loughs;

and it is never found apart from what was once a lough, although it may be that "loughs" which originally existed are now filled with spar. This hard ore is sometimes very curiously mixed with stone.

2. *Dull, reddish-purple ore*, which occurs in moderately hard pieces mixed with softer concretionary ore of a bright red colour, in some of the interstices of which there is a quantity of very soft, red, greasy-looking ore called "smit," which seems to be the same kind of ore as that forming the concretions, but in a powdery condition, and mixed with water. The concretionary ore, on being subjected to the action of the atmosphere, and turned over a few times rather roughly, falls into a powder, which, when moistened, has exactly the appearance of "smit," and leaves the same red greasy stain. Under the microscope it is seen to contain a number of minute particles of quartz, which, in the pre-powdery condition of the ore, occupied cavities therein, similar to those found in the hard blue-purple ore.

This ore is found at the southern end of the Lindal Moor deposit, in part of the Stank deposit, at Yarlside, Crossgates, and elsewhere. The softest of it is known as "puddling" ore. Its composition is as follows:—

	No. 1.	No. 2. Dried at 212° Fahr.
Ferric oxide	77·24	86·50
Protoxide of manganese	·11	·21
Silica	7·36	6·18
Alumina	1·71	·30
Lime	6·08	2·77
Magnesia	·41	1·46
Carbonic acid	4·19	2 96
Phosphoric "	—	trace
Sulphuric "	—	·11
Water	2·82	—
Total	99·92	100·49
Metallic iron	54·06	60·55
Specific gravity	4·04	4·47

The harder pieces of ore, as already mentioned, contain microscopic cavities, some of which are filled with quartz, but many of them are empty. In this ore the loughs are smaller, but more numerous than in the hard compact ore first described. When they contain spar it is generally calcite, very little quartz occurring in them. The soft kidney-like concretions in this ore are frequently found following the contour of included pieces of stone, and sometimes it may be seen in "ginnels" having the same relation to the limestone cheeks.

In this ore, at Gilbrow (the south end of the Lindal Moor deposit), a number of fossils belonging to the Carboniferous limestone have been found, some converted into hæmatite, others only partially so. The forms are similar to those met with at Whitehaven.

3. *Soft, dark ore.* This is the most abundant ore in Furness, being that which is mainly found in the dish-like deposits. It consists of hard pieces of ore like those last described—some of which have the kidney-form—of the size of a man's hand, and less, set in a moderately soft, dark red or brown, and sometimes nearly black matrix consisting of "smit" clay and manganese, the whole mass having a most confused appearance. It contains no loughs, except such as are occasionally found within the harder pieces of it, and these are necessarily very small. Its composition is as follows :—

	1.	2.	3.	4.
Ferric oxide	60·61	69·81	75·35	84·47
Manganese	2·22	1·12	1·49	·22
Silica	21·93	15·38	7·27	6·95
Alumina			2·10	
Lime	·39	·21	·21	·25
Magnesia	·56	·70	·64	·41
Sulphuric acid ...				
Phosphoric „ ...	·03	·02	·03	·03
Loss on ignition ...	3·76	3·44	2·54	1·58
Moisture lost at 212° F.	11·44	10·10	10·00	6·90
Total	100·94	100·78	99·63	100·81
Metallic iron	42·43	48·81	52·75	59·13
Specific gravity ...	3·66	3·78	3·98	4·30

In the Ure pits, near Dalton, a dark ore of this description was found, which contained 15·35 per cent. of peroxide of manganese, and 4 per cent. of titanic acid.

In the other two classes of ore the kidney-like concretions are invariably found immediately adjoining loughs, but in this they are imbedded in the softer ore and altogether apart from loughs.

The distinguishing feature of this ore chemically is its comparatively large percentage of manganese. The second ore described contains a high percentage of lime and carbonic acid, due probably to the presence of limestone. The hard compact ore contains little manganese but a large quantity of silica.

General Features.

When ore is in contact with either shale or sandstone there is a distinct line of demarcation between them, but this is rarely so when it is in contact with limestone or "whirlstone." The junction then is very indefinite, the ore and stone being, as the miners express it, "grown together." The passage from one to the other is by regular gradations. Very frequently the ore for a few inches adjoining the stone has a laminated appearance, that structure being most distinct near to the stone, and becoming less and less so as the distance from it increases. Sometimes between the ore and stone there is a thin parting of clay, but it seldom, if ever, exceeds half an inch. In some cases the stone adjoining the ore, and for two or three feet away from it, is of quite a porous nature, being at one time black and cindery-looking, at another yellow and ochreous or "gossany," or again, it may be a dullish brown.

A most remarkable feature of these deposits, when in the fourth, fifth, sixth, and bottom limestones of the Whitehaven district, is the occurrence in them of partings and nests of shale. Fig. 14 shows several of these partings, as exposed in the No. 5 pit, Eskett Park. The beds between which the partings occur are partly silicious stone, and partly hard

jointy hæmatite, and they have the same dip, both in direction and amount, as the rocks surrounding the deposit. A similar section seen in Salter Hall No. 3 pit is given in Fig. 15. Here again, the beds of ore and the shale partings have the same dip

FIG. 14.—SECTION IN ESKETT PARK NO. 5 PIT. (Scale 8 feet to an inch.)

References—*a* Hard jointy Hæmatite, laminated at *a'*. *b* Whirlstone. *c' c'' c'''* Shale partings.

as the surrounding strata, with which, in fact, the partings are actually interbedded. The pieces of whirlstone *b* and *b''*, which are separated by the partings *c'*, were proved at several points to be connected with, in fact, to form part of, the sur-

FIG. 15.—SECTION IN SALTER HALL NO. 3 PIT. (Scale 16 feet to an inch.)

References—*a* Hard jointy Hæmatite. *b b'* Whirlstone. *c c'* Shale partings. The dotted lines show the workings by which the Section was laid open.

rounding rocks, so that the partings *c* and *c'* are interbedded with the limestone as well as with the ore. The same thing might also be observed at the Crossfield Company's "opencut" (Fig. 16). There the shale bed *f* was seen lying between the ore, and also continuing into the limestone.

Nests of shale are occasionally found surrounded by hæmatite. The horizontal section of these nests is roughly circular, and the laminations of the shale are parallel to the bed planes of the rocks surrounding the deposit.

In Furness these shale partings in the ore are rarely met with, for the very good reason that, as already pointed out, there are few beds of shale in the limestone; still they are met with occasionally in the ore, and the writer has seen sections in the

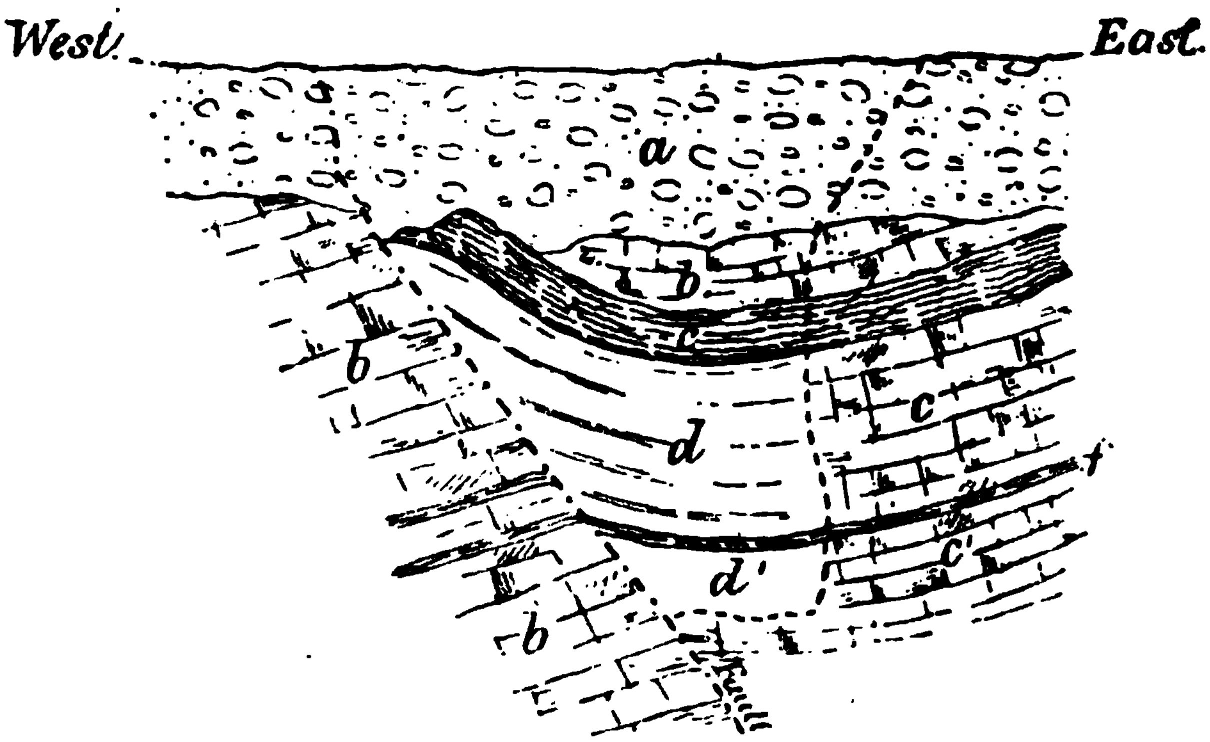


FIG. 16.—SECTION OF "OPENCAST" AT CROSSFIELD. (Scale 40 feet to an inch.)

References—*a* Boulder Clay. *b* Limestone. *c c'* Limestone very Silicious. *d d'* Hæmatite. *e* Red and Grey Shale. *f* Grey Shale. The dotted lines show the sides of the Opencut.

"ginnels" of the Askam deposit, which showed a thin layer of shale interbedded with both the limestone and the ore. He has also seen a section in the same mine showing a thin layer of shale forming the roof of a bed-like piece of ore. He has observed the same kind of thing at the north end of the Lindal Moor vein.

Wherever beds of shale are met with in the ore, which cannot be traced into the surrounding limestone, they have invariably the same dip as the limestone.

Another fact of frequent occurrence which it is desirable

to mention is the shaly nature of the roof of some mines; the shale beds so forming the "roof" are invariably interbedded with the surrounding rocks, as shown in Fig. 17, which is a section of the Scalelands mine.

A fact which the writer has very often noticed in connection with the shale partings, as well as with the "roof" and "sole," when either or both of them are shale, is that the ore in contact with the shale, if that be not black and slaty, is very much softer than it is a foot or so away from it, the softness increasing as the shale is approached.

FIG. 17.—SECTION OF SCALELANDS MINE. (Scale 120 feet to an inch.)

References— *a* Boulder Clay. *b* Carboniferous Limestone. *c' c'' c'''* Grey Shale. *d* Hæmatite.

In some of the deposits the ore has quite a bedded appearance. This feature was very well displayed in Todholes quarry, below the shale beds which ran through the ore. It might also be seen in the Cleator Iron-ore Company's "opencut" near Jacktrees. At a distance, the ore in these deposits had the appearance of a red-stained limestone, such as may be seen near Park mines in Furness. The dip of the ore beds corresponded exactly, both in direction and amount, with that of the adjoining limestone on the same side of the fault. Sometimes where the ore is bedded in this way the alternate layers are hard and soft.

Another feature which might also be seen at the Cleator

Iron-ore Company's "opencut" just mentioned, is the existence of joints in the ore somewhat similar to the two sets of joints (beside the bed joints) by which all rocks are more or less intersected. One set of these joints ran nearly east and west, the other nearly north and south. These joints are not strong and persistent such as the joints found in limestone, or even in slate, but are quite short and interrupted. So far as the writer's experience goes, they only occur in the hardest ore, and those joints having an east and west direction are more numerous and stronger than those running at right angles to them.

In some of the deposits the ore is interrupted by masses of stone, which frequently have an elongated form, their longer axis having a direction corresponding very nearly with the north and south joints of the limestone. These stony masses are usually connected either at one end, or both, or at the bottom or top, with the main body of limestone in which the ore lies; that is to say, they project into the ore from the surrounding limestone. Some smaller pieces of stone, having the shape of rough irregular spheres, are frequently embedded entirely in the ore.

In some of the dish-like deposits of Furness large masses of red and white sand are met with. In the Park deposit there is a very large quantity of it; so much, in fact, that it is worked and sent to Barrow for use at the blast furnaces. The horizontal form of these sandy masses at Park is shown in the two plans of that deposit given in Figs. 11 and 12. Vertically they are as irregular as in plan, but are more or less continuous from the under side of the drift down nearly to the 70 fathoms level. In the 60 fathoms level there are blocks of red sandstone, which in the centre cannot be distinguished from the St. Bees sandstone. On the outer side of these blocks the sandstone is less hard and arranged in concretionary layers, which are softer and softer outwards, until they disappear altogether in a mass of loose sand.

Frequently in the dish-like deposits of Furness, and occasionally in those having a vein-like form, masses of

red, yellow, and whitish clay are met with. Sometimes this clay is quite hard, and then it receives the name of "hunger."

The clay masses usually, but not invariably, occur around the outside of the ore between it and the limestone, or, as in the case of the Park deposit, between the ore and the sand. They are not continuous but interrupted. Sometimes two or three fathoms of clay may be found between the ore and the limestone. At other times, the ore can be seen abutting against the stone. In the latter case the limestone has a rounded outline, and is often decomposed to a depth of nearly an inch; or, to use the miners' expression, it has then a "crust" on it.

In the deposits containing hard, compact ore, the stone and ore at their junction are often blended into one another in such a way that they seem to be "grown together," as is often the case in the Whitehaven district. This appearance is occasionally met with in the deposits containing soft ore, but only in small pieces.

In many instances, particularly in the Mousell mine, the limestone on the outside of the clay appears to be very much broken up, and between the disjointed masses of stone some of the clay just spoken of has penetrated. Sometimes in the clay, surrounding the ore, vegetable matter is found, particularly in the deposits at Crossgates. In one or two of the mines there pieces of flattened exogenous wood, 6 to 8 inches diameter, have been found embedded in the clay on the outside of the deposit; in one case at a depth of 24 yards from the surface, and in a mine which is overlaid by only about 4 yards of drift. Occasionally these clays enclose small *angular* patches of white sand, and also angular, sub-angular, and rounded fragments of hæmatite. There is also associated with the clay a substance called by the miners "black muck," an analysis of which is given on next page.

ANALYSIS OF BLACK MUCK.

Water at 212° Fahr.[1]	1·11
Water combined	5·56
Peroxide of iron	37·88
Alumina	2·86
Manganese oxide	11·97
Carbonate of lime	2·34
Magnesia	·45
Sulphuric acid	
Phosphoric "	1·13
Insoluble silicious matter	36·70
	100·00

The miners sometimes call the dark *vegetable* matter, previously alluded to, "black muck" also; but the two substances to which they give that name, it need scarcely be said, are entirely different, except in outward appearance.

Fossils are sometimes met with in the ore, but they are very rare and restricted in variety. They are partially or wholly converted into ore. The forms found by the writer include a nautilus, and several species of brachipods and corals, all belonging to the carboniferous limestone. In a specimen of coral in the writer's possession, the stems for about two inches in length are converted into hæmatite, the remainder being carbonate of lime, and there is a gradual transition from the hæmatite to the carbonate of lime. It has been several times asserted, that certain species of carboniferous plants had been found in the ore, but upon close inquiry it turned out that there was not sufficient evidence to show exactly where they came from; most probably it was from the "grit-roof," as the deposit in which these plants were alleged to have been found had such a "roof."

Before leaving this part of the subject it is necessary to notice the distribution of the deposits. In the Whitehaven

[1] This would have been very much greater if the analysis had been made soon after the sample was taken out of the mine. Being kept for about six months in a very dry place before it was analysed, a considerable amount of water was lost.

district this is shown on Plate I. In Furness they are mainly concentrated around the high ground about Haume, their number and extent decreasing as the distance from Haume increases, the only exceptions being the deposits at Stainton, Stank, and Yarlside, which are adjacent to the two great lines of fracture traversing the district.

Associated with the ore of these deposits are frequently found crystals of calcite, crystallised and granular dolomite, and crystals of quartz, more rarely barite, either laminated or in tabular crystals, also arragonite and pyrite. In Fletcher pit, at Bigrigg, fluorite is not uncommon. It has also been found in Lord Leconfield's Bigrigg mines. These latter mines have also yielded a quantity of hausmannite. It occurs in loughs in the hæmatite. Göthite has also been found in the same loughs.

FIG. 18.—SECTION OF ORE-BED AT MILLYEAT. (Scale 16 feet to an inch.)

References—*a* Grey sandstone sometimes with a purple tint. *b* Red shale. *c c' c''* Hæmatite, 1, 3, and 11 inches thick respectively. *d* Purple grey and yellow shale (clayey). *e* Liver-coloured shale.

In Birks mines, pyrolusite has been found, in the Eskett mines manganite, and in Salter Hall mines crystallised siderite and xanthosiderite. This latter mineral occurs along joints in the hæmatite. In Hodbarrow and Yarlside mines a few pieces of hæmatite have been found presenting the form of irregular clusters of hollow cubes. The ore in these situations seems to have encrusted either pyrite or fluorite which has been subsequently removed.

Deposits in the Upper Coal Measures. The only deposit of hæmatite in these rocks that has been worked is that which occurs at Millyeat near Frizington, in the northern part of the district. It is some time since it was worked, and no record appears to have been kept of what was done, so that there is not very much known about it. The ore occurs in the form of a bed, as shown in Fig. 18.

Both above and below the ore there is a thick bed of liver-coloured shale (6 and 7 of section given in description of coal measures). The ore, when seen in the bottom of the stream that runs down by the mill, is split up into three minor beds by intermediate layers of soft shale, but on the south-eastern side of the valley, where it was worked some years ago, it was still more divided, as shown by the following section :—

	Ft.	In.		In.		Ft.	In.
1. Ore	1	0	...	0			
2. Clay	0	0	...	1			
3. Ore	0	2	...	0			
4. Clay	0	0	...	0¼			
5. Ore	0	1½	...	0			
6. Clay	0	0	...	0¾			
7. Ore	0	0½	...	0			
8. Clay	0	0	...	4			
9. Ore	0	2½	...	0			
	1	6½	+	6¼	=	2	0¾

The quality of the ore is very variable, but the best of it is about as pure as any that has been found in the district, as the following analyses will show :—

	No. 1.	No. 2.
Peroxide of iron	97·85	96·40
Phosphate of iron	·71	·80
Silica	1·44	1·20
Lime	trace	1·60 (Lime and Magnesia)
Magnesia	—	
	100·00	100·00
Metallic Iron	68·5	67·48

The average specific gravity is about 4.

The appearance of the best ore, both as regards colour and texture, is very much like the finest tool steel, but the poorer ore is quite earthy-looking, and of a bright red colour. It contains a large proportion of lime. In some cases, thin irregular layers of limestone are actually seen in it, and in some places it is very much intersected by joints. The position of

this ore, from stratigraphical considerations, is most probably that of the Spirorbis limestone[1] of Ayrshire, Lancashire, and Staffordshire, although the writer has not been able to find any specimens of that organism in either the ore or the limestone with which it is associated.

[1] This conclusion was first arrived at by the Author in 1878. Recently Mr. W. Brockbank has discovered *Spirorbis Carbonarius* at Frizington Hall, about half a mile south of Millyeat.

CHAPTER III.

THE IRON ORES OF CORNWALL, DEVON, AND WEST SOMERSET.

LITERATURE.

1. "The Iron Ores of Exmoor," by W. W. Smyth. *Geologist* 1858.
2. "The Iron Mines of Perran," by W. W. Smyth. *Transactions of the Royal Geological Society of Cornwall,* vol. iii.
3. "Brendon Hills Spathose Iron Ore and Mines," by Morgan Morgan. *Proceedings of South Wales Institute of Engineers,* 1868.
4. "The Perran Iron Lode," by N. Bryant. *38th Annual Report of the Royal Cornwall Polytechnic Society,* 1871.
5. "Iron Ores of Cornwall," by J. T. Woodhouse. *Journal of the Iron and Steel Institute,* vol. ii., p. 27, 1871.
6. "The Iron Ores of Cornwall, by J. H. Collins. *Mining Magazine and Review,* vol. i., p. 77, 1872.
7. "On the Great Perran Lode," by J. H. Collins. *Miners' Association, Cornwall and Devon,* 1873.
8. "The Perran Iron Lode in Cornwall," by Charles Parkin. *Transactions of the North of England Institute of Mining and Mechanical Engineers,* 1878.

ALTHOUGH these counties contain a considerable quantity of iron ore of different kinds, yet their output has never risen to any economic importance, as will be seen

on reference to the statistics in Part I. They will therefore be described very briefly.

The rocks, in which most of the ores occur, belong to the Devonians; but the area occupied by these rocks has been invaded by several large masses of granite, probably of early Permian age; in which, also, iron ore is found.

The Devonians have been arranged into three divisions as below:—

Upper.	*Pilton and Pickwell Down Group.* Grey slates with layers of impure limestone, passing downwards into red, brown, and yellow sandstones, which are micaceous and flaggy at the base.
Middle.	*Ilfracombe Group.* Grey unfossiliferous slates passing downward into calcareous, fossiliferous slates and limestones which rest on sandstones, grits, and conglomerates.
Lower.	*Lynton Group.* Soft slates with thin limestones and sandstones resting on micaceous sandstones.

Excepting a few dish-like deposits in the limestone, near Brixham, the ores are mostly found in veins, some bedded, others apparently on the lines of faults. The principal varieties of ore that have been worked are (1) siderite, (2) limonite, (3) hæmatite, and (4) magnetite. The first is perhaps never found without the second being present in the same vein, so that these two varieties will be most conveniently considered together; and perhaps the best example of a vein containing them is that worked on Brendon Hills, in West Somerset, by the Ebbw Vale Company, at Raleigh's Cross mine.

SIDERITE AND LIMONITE.

The rocks of Brendon Hills belong to the Middle Devonian. Adjoining the vein just alluded to they have a slaty character, and are locally known as "killas." They are grey near the surface, but become greenish and bluish-grey in depth. The direction of the vein is about N. 55° W. and

S. 55° E., and it hades southward at about 45°. Like all veins its width is variable, ranging from a few inches to over 25 feet, and there are long lengths of it quite barren. On the footwall, as in many veins in the Devonians of Cornwall and Devon, there is a variable thickness of "capel," the local name for a quartzose rock when occurring in this, or a similar, position. The ore, in places, is split up in an irregular manner by "horses" of "killas," as is the case with perhaps all veins of a similar character.

The upper part of the vein contains cellular limonite, with some hæmatite, the former being locally called brown and black ore and the latter red ore; but at depths, varying from 40 to 260 feet, in different parts of the lode, cores of siderite begin to appear in the limonite. These cores become larger as the depth increases, and on reaching an undulating line ranging from about 160 to 310 feet below the surface, the entire vein, in the ore-bearing portions, is filled with siderite or white ore, which continues downwards as far as the vein has been worked, except for a few pockets of "potty" and brown ore, by which it was interrupted, a few feet below the line of its first appearance. "Potty" ore is the local name applied to cellular limonite containing cores of siderite or white ore.

The composition of the ores is shown by the subjoined analyses:—

	Siderite.	Limonite.
Peroxide of iron	·81	73·71
Protoxide of iron	43·84	
" " manganese	12·64	10·80
Lime	·28	·15
Magnesia	3·63	2·66
Carbonic acid	38·86	·14
Water	·18	11·06
Insoluble residue	·08	1·56
	100·32	100·08
Metallic iron	34·67	51·59
Specific gravity	3·68	4·05

The siderite is cellular to a small extent, the limonite very much so. The latter is frequently botryoidal adjoining the

cavities. Some of the cavities contain crystals of göthite psilomelane and manganite.

Limonite also occurs in dish-like hollows in Devonian limestone, belonging to the middle group, near Brixham. Those deposits present most of the characteristics, so far as form goes, of similarly placed deposits in Furness. They occur just below the drift, in irregular hollows in the limestone; and the ore is very much broken up and mixed with detrital matter, which has evidently been washed down from the surface.

The quality of the ore they yield is shown below:—

Peroxide of iron	69·58
Silicious matter	14·38
Phosphorus	·10
Sulphur	·15
Water	14·39
Organic matter	1·40
	100·00
Metallic iron	48·70

A large vein yielding both these ores has been worked at Perran, in Cornwall; and numerous veins of limonite only have been partially wrought in all the three counties. These, in all probability, if worked deeper, would, like the Brendon Hills veins, change into siderite. A vein of limonite worked at Nanjeath, St. Stephen's, near St. Austell, yielded ore of the quality indicated by the annexed analysis:—

Ferric oxide	77·83
Manganous oxide	0·17
Silica	12·43
Alumina	2·19
Lime	·14
Magnesia	trace
Phosphoric acid	·63
Sulphur	trace
Water	7·05
	100·44
Metallic iron	54·48

HÆMATITE.

A good example of a deposit of this ore is the vein near Knightor and Treverbyn, about four miles north-east of St. Austell, Cornwall. It occurs in the granite. The direction of the vein is north and south (magnetic), and it has very little hade, being nearly vertical. The width of the ore varies from an inch to 10 or 12 feet, and there are long stretches in the vein which are quite barren. The cheeks are much decomposed for a few fathoms near the surface, but assume more and more of the normal character of the granite as the vein is worked downwards. Irregularly-lenticular ribs of granite occasionally appear in the vein surrounded by ore. Near the surface, where the ore is softer than it is below, and where these granite ribs are so much decomposed as to have lost all coherence, it is most difficult, in working, to keep the ore free from silicious and aluminous matter; so that the quality of the ore, as it was sent to the market, never equalled that shown by analysis of average samples taken direct from the lode. One such analysis is here given:—

Ferric oxide	83·29
Manganous oxide	·08
Silica	13·86
Alumina	1·02
Lime	·14
Magnesia	·08
Phosphoric acid	·02
Sulphuric acid	·02
Water and carbonic acid	1·19
	99·70
Metallic iron	58·30

A vein of hæmatite was also worked in the Devonian limestone at Sharkham point, Devonshire.

Dish-like deposits of hæmatite are also found in this limestone occasionally. One, worked in a small way, at Ingsdon, near Newton Abbot, produced ore of very good quality, as shown by the following analysis of a piece of it:—

Peroxide of iron	85·00
Oxide of manganese	·20
Silica } Alumina }	11·20
Water	3·50
	99·90
Metallic iron	59·5

MAGNETITE.

This ore has been worked at several places in a small way. For the purpose of illustration, a short description will be given of a vein worked at South Terras, near Grampound Road, Cornwall. The rock forming the walls of the lode is amphibolite, and there is a strong "elvan" course in close proximity to the hanging wall. The vein has a direction bearing about N. 34° E. and S. 34° W., and dips to the north-west at about 40°. When seen by the writer the vein had not been much worked, but it contained excellent ore for a width of about six feet. In addition to this, there was about two feet of poorer ore adjoining the hanging wall, which needed concentration before it could be sent to the market, as it was much mixed with hornblende. This deposit is a bedded vein having the same hade as the strata in which it lies.

The composition of the ore is indicated below :—

	No. 1.	No. 2.
Magnetic oxide of iron	84·24 ...	
Peroxide of iron	3·84 ...	69·36
Protoxide "	...	18·36
Protoxide of manganese	1·06 ...	·18
Silica	7·51 ...	7·44
Alumina	1·35 ...	·86
Lime	trace ...	2·10
Magnesia	trace ...	·14
Phosphoric acid	trace ...	·03
Sulphuric "	trace ...	trace
Water	2·00 ...	1·53
	100·00	100·00
Metallic iron	63·67 ...	62·83

As already said, none of these ores have yet been worked extensively, but it is very likely that they will be sought after as the more abundant ores of West Cumberland, Furness, and Bilbao become exhausted.

CHAPTER IV.

THE LIMONITES OF THE FOREST OF DEAN AND SOUTH WALES.

THE Forest of Dean is perhaps the most interesting iron-ore district of Britain from the archæologist's standpoint, but from that of the geologist it cannot compare with West Cumberland.

Very little has been written on the limonite deposits of either the Forest or South Wales. The following papers are all that have come under the notice of the writer :—

On the Iron Ores of the Forest of Dean in "Papers on Iron and Steel," by David Mushet, 1840.

"The Ironstone Formation of the Forest of Dean," by Dr. J. W. Watson. *The Geologist*, 1858.

"The Hæmatite Deposits of Glamorganshire," by Dr. J. W. Watson. *The Geologist*, 1859.

In the "Iron Ores of Great Britain," *Geological Survey Memoir*, published in 1861, there is a very short notice of the Llantrissant deposit.

"The Forest of Dean Coalfield," by H. R. Insole and C. Z. Bunning. Vol. vi., no. 5, *Transactions of the British Society of Mining Students*.

"The Hæmatite Deposits of the Southern Outcrop of the Carboniferous Limestone of South Wales," by Stephen Vivian. *Proceedings of the South Wales Institute of Engineers*, vol. xiv., no. 3.

"The Mwyndy Mines," by W. Morgan. *Proceedings of the Cardiff Naturalists' Society*, 1870.

Geological Structure.

Forest of Dean. The geological structure of the Forest of Dean is comparatively simple. The rocks represented belong to the carboniferous system, and consist of coal measures, millstone grit, and carboniferous limestone, the latter resting on the Devonians. They form an irregular basin, the centre of which is occupied by the coal measures; the millstone grit and carboniferous limestone coming to the surface in bands of varying width along the rim of the basin. On the south-eastern side these latter rocks thin out, and disappear entirely, being overlapped by the coal measures, which, for a distance of about three miles, rest directly on the Devonians. The limestone band is very much narrower, and more regular in width on the east than on the west side of the basin. This is owing to the difference of dip, which on the east is about 60° with the horizon, whilst on the west and north it is only from 5° to 15°.

The millstone grit consists of coarse grit (known locally as "farewell rock") and sandstone, with thin beds of marl. It has a maximum thickness of about 680 feet. In the lower part of this formation there is a deposit of limonite known as the "sandstone vein," or "sandstone mine formation," which has been worked to a limited extent on the west side of the Forest. It varies in thickness from 6 inches to 8 feet.

The carboniferous limestone has a maximum thickness of about 650 feet; the upper 460 feet being mostly limestone with thin beds of shale. The lower part (190 feet thick), called the lower limestone shale, consists largely of shale with thin beds of limestone. Near the upper part of the thick limestone occurs most of the iron ore that is raised in the Forest of Dean. A section of some of these beds as they occur on the east side of the Forest is as below :—

Millstone Grit.	Thickness.
Whitehead limestone (grey) with shale partings up to 12 inches thick.	15—20 yds.
Crystalline limestone, locally called "crys," or "crease," or "mine measures," containing large, irregular deposits of limonite.	10—20 „
Little red limestone	2—4 feet.
Grey limestone	10—15 yds.
Main red limestone	80—95 „

Between the whitehead limestone and the crys there is a stone of variable thickness, but seldom exceeding 2 or 3 feet, locally called "lidstone," consisting of "crys" and shale mixed together in a somewhat confused manner.

The limestone both above and below the "crys" is distinctly bedded, but the crys itself, as a rule, shows no signs of bedding, although traces of it may be seen occasionally. It is in the crys that the bulk of the ore found in the Forest occurs, but smaller deposits are found between the grey and the main red limestones. The ore hitherto worked has been obtained along the outcrop of the crys and associated beds, and down to a depth on the east side of the Forest of about 225 yards, and to about 120 yards on the west side. The course of the ore-bearing rocks on the surface is known as the "mine train." It is marked by numerous old workings, locally called "scowles," many of which are doubtless the work of the Romans.

South Wales.—The South Wales deposits also occur in the carboniferous limestone, and mainly along the southern edge of the coalfield between Rudry and Llanharry. The lower coal measures, consisting of blue shale, locally called "clod," rest directly on the limestone near Llantrissant. The latter rock is of considerable thickness, and very little split up by shale. Both coal measures and limestone dip northward at an angle of about 35° with the horizon.

Resting transgressively across the eroded edges of the rocks last named are considerable patches of dolomitic conglomerate belonging to the lower part of the upper Trias, consisting

chiefly of angular fragments of limestone, with which, in places, a large quantity of iron ore (limonite) is mixed up.

As in the Forest of Dean, the ore here is mainly confined to the upper beds of limestone, the larger part of that hitherto worked having come from the beds just below the coal measures between Llanharry and Mwyndy, but a considerable quantity of ore has been worked in the middle and lower beds at Garth and Rudry respectively.

Form and Inner Nature of Deposits.

Forest of Dean.—Both in the Forest of Dean and South Wales the deposits have the form of filled caverns. In the former locality, as already mentioned, they occur in the crystalline limestone called "crys." They are met with in all parts of this bed, sometimes being along the "lidstone." At other times they follow the "underedge," as the stone is called which underlies the crys, or, they may extend from lidstone to underedge. Frequently they are entirely within the crys and towards the centre of it. They are of all sizes, up to chambers which would hold 60,000 tons of ore. At least one deposit has been met with as much as 350 yards long, 12 to 14 yards high, and nearly the same in breadth. The chambers or "churns," as they are called locally, are in some parts of the "mine measures" very numerous. They are then united to one another, as a rule, by small strings or "leads" of iron ore. The largest "churns" occur near the surface, and they become less and less in depth. Those near the surface, that have had their upper parts removed by denudation, have the appearance of the dish-like deposits of Furness. On the west side of the Forest, near Clearwell, for example, where the limestone beds have a low angle, these dish-like deposits have been numerous, and all worked "opencast." An examination of the old "scowles" in that neighbourhood gives one a very fair idea of the forms of the "churns," but they throw no light on the inner nature of the deposits, as all the ore has been removed from them years ago; some of it, no doubt, by the Romans.

As is the case with all similar deposits in limestone, the churns have very irregular outlines, tongues of ore protruding into the limestone, and *vice versâ*. These tongues invariably follow one or other of the two sets of vertical joints.

Figure 19 is a section of the Westbury Brook mine on the east side of the Forest. This is the deepest iron mine in the Forest, and the section will give a better idea of the forms of the churns and their mode of occurrence in the crys than many words.

FIG. 19.—SECTION OF WESTBURY BROOK MINE. (Scale 400 feet to an inch).

References—*A* Superficial Deposits. *B* Millstone Grit. *C* Whitehead Limestone. *D* Crys with churns at Limonite. *E* Grey Limestone. *F* Red Limestone.

Between the grey and the main red limestone, there frequently occurs a joint of ore, as shown at *e* in Fig. 19, large enough to be worked. A joint of this kind has been followed at Westbury Brook for a length of a quarter of a mile. Here and there it was connected by cross-ore joints with the churns in the crys.

A careful consideration of the preceding remarks will show

the absurdity of the attempts that have been made to fix the yield per acre of these deposits. Assuming they had been scattered through the crys with anything like regularity—which they are not—it is quite clear that the production per acre must have varied very seriously owing to the great variations in the dip of the crys and its associated beds. Take two extreme cases, one in which the beds are level, the other where they are vertical; it must be apparent to any one that the latter would contain, in a given area, a much larger quantity of ore than the former.

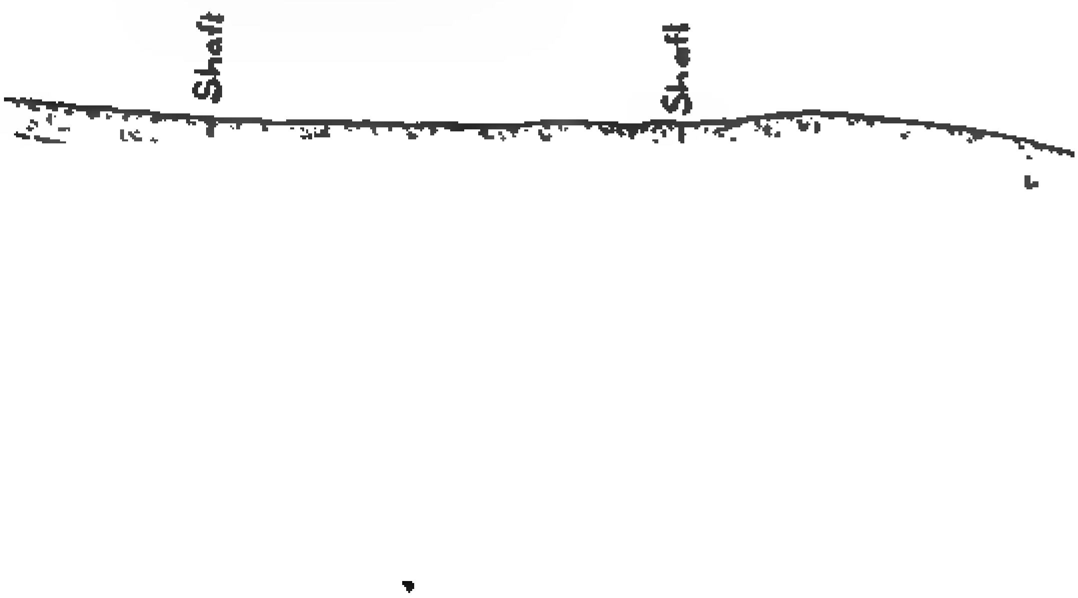


FIG. 20.—SECTION OF TRECASTLE DEPOSIT. (Scale 240 feet to an inch).

References—*A* Superficial Deposits. *B* Dolomitic Conglomerate. *C* Shale. *D* Carboniferous Limestone. *E* Limonite.

South Wales.—The forms of the South Wales deposits are more dependent upon their position than those of the Forest. If they are immediately under the coal measures, as at Trecastle, Bute, and Mwyndy, they assume a vein-like form with a covering of drift, or drift and conglomerate, having the coal measures and sometimes the dolomitic conglomerate as a hanging wall, and the carboniferous limestone as a "lying" or foot wall; being, moreover, of considerable length as compared with the breadth or depth. Figure 20 is a cross section of the Trecastle mine

after Mr. S. Vivian. The course of the deposit here, as also of those at Bute and Mwyndy, was nearly east and west, dipping to the north under the coal measures at an angle of about 35°. The hanging wall was fairly regular, but the foot wall was very irregular, so that the deposit varied much in breadth; moreover, tongue-like projections of ore extended here and there from the main body, in a southern direction into the hanging wall, for a considerable distance—as much as 60 feet in one place. These tongues or branches followed the lines of jointing in the limestone. Some of them occurred near the surface, and the upper part had been removed by denudation,

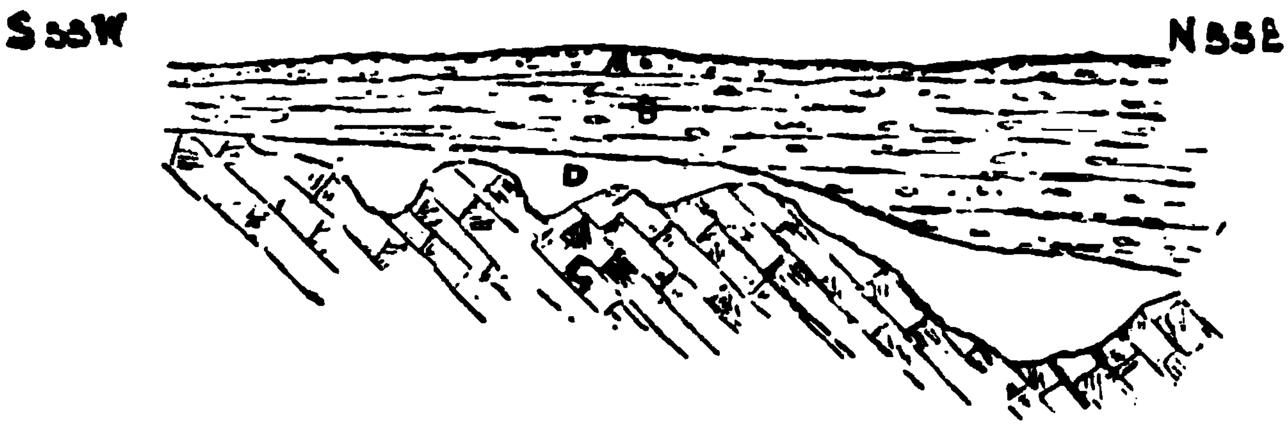


Fig. 21.—Section of Llanharry Deposit. (Scale 50 feet to an inch.)

References—*A* Superficial Deposit. *B* Dolomitic Conglomerate. *C* Carboniferous Limestone. *D* Limonite.

so that they looked like filled troughs. The upper part of the ore at Mwyndy and Bute was worked opencast, the lower part by mines.

Where the deposits are entirely in limestone, except for the covering of drift, as at Garth, they have more the appearance of the churns in the Forest of Dean; and, in the main, have the same dip as the limestone, though, at times, they cut across the beds of that rock.

The South Wales deposits are sometimes overlain by the dolomitic conglomerate, as shown in Fig. 21, which is a section of the ore as seen at Llanharry.

Inner Nature of Deposits.

Forest of Dean. When we come to look closely at the contents of the deposits we find, in the Forest of Dean, three principal kinds of ore.

First.—*Brush ore.* A hard, dark brownish-purple cellular limonite. The walls of the cavities in it are frequently mammillated, others are lined with crystals of calcite or quartz. Sometimes they are filled, or nearly so, with crystallised calcite. The ore is then known locally as "grey burler." When "brush" is mixed with brown-ochry ore it is known as "brown burler." Frequently it presents a stalactitic form, numerous small stalactites occurring within the cells, which are so abundant in this ore. The walls of the "churns" are often lined with brush, and when in that situation it is known as "clingings," or "scabbings." The larger cavities in the hard ore are called "pooches."

Second.—*Smith ore.* Also limonite, but in a powdery and gravelly condition.

Third.—*Grey ore.* A low grade ore composed of "brush" and dolomite, the latter mineral having apparently filled up the interstices of what was once very cellular stalactitic brush.

The composition of these ores is given in the following table:—

	Brush.	Smith.	Grey.
Peroxide of iron	90·05	89·76	48·98
Protoxide of manganese ...	·08	·04	·16
Silica	1·07	1·57	·86
Alumina	—	·63	·12
Lime	·06	·49	14·07
Magnesia	·20	·40	10·21
Carbonic acid	—	—	20·75
Phosphoric acid	·09	·13	·06
Water	9·22	7·05	5·18
Total	100·77	100·07	100·39
Metallic iron	63·03	62·83	34·28

These are all picked samples, the two latter analyses especially showing in excess of the average metallic yield of the respective classes of ore. In the case of Smith ore the average yield of iron ranges from 50 to 54%, whilst in grey ore it is not unfrequently as low as 18%.

The specific gravity of the brush is about 3·65, of the "grey burler" 3·17, of the "brown burler" 3·04, and of the "grey" ore 2·83.

The three kinds of ore are not kept separate in working, but are sent to the market mixed together. They then yield from 35 to 40 per cent. of metallic iron. The following analysis is an average of 160 samples.

Ferric oxide	51·984
Silica	17·934
Alumina	2·859
Lime	1·906
Magnesia	·280
Potash	·029
Carbonic acid	2·512
Phosphoric „	·160
Sulphuric „	·095
Water combined	8·847
„ hygroscopic	13·360
Total	99·966
Metallic iron	36·33

The "Smith" ore forms about two-thirds of the whole. It ofen occurs with alternating irregular layers of red and yellow ocre, which give the deposit quite a bedded appearance. In sone places these layers are nearly level; at other parts of a deosit they have the same inclination as the "crys."

Some gothite and turgite are also met with in the deposits, bu not much.

Among the ore, in places, masses of white sand and fine togh clay occur, similar to those found in the Furness deosits.

South Wales. In the South Wales deposits we also meet

with the purply-brown cellular limonite, in places stalactitic and botryoidal; but the greater part of the ore in some deposits, as, for instance, that at Trecastle, is softer, and yellow or brownish-yellow in colour. Many of the smaller cells in the harder ore have been *filled* with quartz and calcite. The larger cavities are lined with these minerals. Some of the harder ore found at Trecastle is hæmatite, locally known as "blue iron." At Mwyndy there is rather more of this ore. It occurs in close association with the hard cellular limonite.

The chemical composition of the ores is shown by the following analyses:—

	Limonite (Trecastle).	Hæmatite (Mwyndy).
Peroxide of iron	74·71	70·57
Protoxide of manganese	·19	·52
Silica	3·86	18·36
Alumina	1·90	1·57
Lime	5·56	3·56
Magnesia	·94	1·31
Carbonic acid	4·90	2·71
Phosphoric acid	·01	·13
Sulphur	·02	·30
Water combined	7·64	—
„ hygroscopic	0·24	·66
Total	99·97	99·69
Metallic iron	52·29	49·39

The specific gravity of the "blue iron" is about 4·1, ad of the average brown and yellow ore from 3·27 to 3·63.

A little pyrite and some barite, as well as quartz and calcie, are found associated with these ores.

CHAPTER V.

THE SIDERITE AND LIMONITE OF ALSTON AND WEARDALE.

THE tract of country intersected by Weardale, the two Allendales and the South Tyne, is occupied by Yoredale rocks. These rocks are traversed by numerous veins, from which large quantities of galena have been extracted; in fact, at one time, this was the most important lead-producing area in Britain. Associated with these lead veins, but not worked separately until about forty-eight years ago, are the siderite and limonite under consideration, which are locally known as "rider." Very little has been written about these ores; indeed, their comparatively small economic importance has left them almost unnoticed.

The following are the only papers known to the author in which they are described, even briefly:—

Geological Survey Memoir, "Iron Ores of Great Britain," Part 1, by W. W. Smyth, 1856.

"On the Occurrence of Lead, Zinc, and Iron Ores in some Rocks of Carboniferous Age in the North-West of England," by C. E. de Rance. *Geological Magazine*, vol. x., 1873.

The nature of the rocks occurring in the area under consideration, and which belong to the Yoredale series, will be understood from the section below.

Local names used in the section—

Plate	=	shale.
Hazle	=	sandstone.
Grey-beds	=	thin alternating beds of sandstone and shale.
Sill	=	hard, laminated micaceous sandstone.
Girdle beds	=	sandstone, thin alternating layers, hard and soft.

SECTION OF YOREDALE ROCKS, AS DEVELOPED AT ALSTON.

Base of Millstone Grit.	Ft.	In.
Fell Top limestone	4	6
Coal	0	8
Hazle, or upper coal sill	12	0
Plate	30	0
Hazle, or Whetstone sill	9	0
Plate	12	0
Hazle	12	0
Plate	7	0
Upper slate sill	24	0
Plate	7	6
Lower slate sill	21	0
Plate	30	0
Hazle, or hard dry slate	9	0
Plate	21	0
Ironstone and coal	4	6
Firestone	33	0
Plate	24	0
White tuft	11	0
Plate	17	0
Girdle bed	6	0
Plate	13	0
Pattinson's sill or hazle	12	0
Plate	18	0
Little limestone	9	0
Plate	18	0
Coal	1	6
High coal sill	12	0
Plate	7	6
Coal	1	0
Low coal sill	10	0

Base of Millstone Grit.	Ft.	In.
Plate ...	18	0
Great limestone (uppermost 16 feet called "Tumbler Beds")	63	0
Tuft or water sill	9	0
Plate ...	21	0
Small limestone	1	6
Quarry hazle	30	0
Plate ...	33	0
Sill bed	7	6
Four-fathom limestone	24	0
Nattriss Gill hazle	18	0
Plate ...	33	0
Three-yards limestone	9	0
Six fathoms hazle	36	0
Plate ...	10	6
Five-yards limestone	7	6
Slaty hazle	12	0
Plate ...	18	0
Scar limestone	30	0
Plate ...	3	0
Hazle ...	3	0
Coal ...	0	6
Plate ...	7	6
Hazle ...	12	0
Plate ...	3	0
Hazle ...	2	0
Plate ...	9	0
Hazle ...	2	0
Plate ...	2	0
Hazle ...	1	0
Cockle-shell limestone	2	0
Hazle ...	2	6
Plate ...	1	0
Hazle ...	9	0
Plate ...	5	0
Single-post limestone	6	0
Plate ...	3	0
Greystone ...	3	0
Plate and grey beds in alternating layers	54	0
Tyne-bottom limestone	24	0
Total ...	932	8
Aggregate thickness of the limestone ...	180	6

The strata have a very slight inclination to the east; and the more important beds, especially the limestones, are fairly constant over a large area.

A little way below the Tyne-bottom limestones (but over it in adjoining districts), is an intrusive mass of basalt, known as the "whin sill." It follows the bed planes of the sedimentary strata over large areas, and, on that account, has, until a few years ago, been looked upon as contemporaneous with that strata. By many persons this rock is supposed to have had an important influence in the formation of the mineral veins of the district; but such an idea is quite untenable, for the veins cut through the basalt, and that rock is thrown by the faults, along which the veins have been formed, just as the other rocks are, showing that the faults, and therefore the veins, are younger than the basalt. The age of the basalt is probably Early Permian.

The majority of the veins traversing these rocks are usually divided into (1) *right-running veins*, which course approximately east and west; and (2) *cross veins*, having a nearly north and south direction. But there are some veins having a course between these two. They are called *quarter-point veins*. The east and west veins appear to be the older of the two main sets, for they are frequently shifted by the cross veins.

Most of the veins are on the lines of faults, some having only a few feet of throw, others a great many fathoms.

The iron ores found in the veins are of three principal kinds, known locally as (1) white, (2) grey, and (3) brown. The first two are siderites, the last limonite, which has clearly resulted from the alteration of siderite. Their chemical constitution is shown by the following analyses:—

	Siderite.			Limonite.	
	No. 1.	No. 2.		No. 3.	No. 4.
Peroxide of iron ...	—	·82	...	71·16	65·90
Protoxide „ ...	49·47	49·79	...	·04	—
Dioxide of manganese	—	—	...	—	6·45
Proto manganese ...	2·42	1·92	...	6·59	—

	Siderite. No. 1.	Siderite. No. 2.		Limonite. No. 3.	Limonite. No. 4.
Silica	4·93	2·00	...	4·04	13·00
Alumina	trace	1·10	...	2·37	1·00
Lime	3·47	3·98	...	·69	trace
Magnesia	3·15	2·83	...	1·96	,,
Carbonic acid	37·71	37·23	...	·10	·17
Phosphoric ,, ...	trace	trace	...	·22	trace
Sulphur	·08	·04	...	—	—
Water	—	·26	...	12·43	12·70
Total	101·23	99·97	...	99·60	99·22
Metallic iron	38·56	39·25	...	49·81	46·13

The specific gravity of the spathic ore may be taken at 2·88 to 3·5, and the limonite at 3 to 3·6. The siderite, or white, or grey ore, contains numerous cavities called "lochs" or "lofs," which are lined with crystals of one or more of the following minerals: siderite, quartz, calcite, fluorite, dolomite, etc. Some of the lofs, which originally existed in this ore, appear to have been subsequently filled, or partially so, by siderite, which has invested the fluorite and other crystals that had previously formed in the walls of the lofs.

The limonite, or brown ore, is very cellular, much more so than the siderite; and it has sometimes a mammillated form in the walls of the cells. Frequently this brown ore forms the walls of the lofs in the siderite; indeed, it seems as if the alteration from the carbonate to the peroxide had in a great measure proceeded from these lofs. The walls of lofs in the brown ore are also lined with the minerals mentioned above, as occurring in the cavities of the siderite. Both kinds of ore have a considerable quantity of galena scattered through them, in places where the veins happen to be lead-bearing; in other parts they are quite free from this mineral. Sometimes it occurs in solitary cubes; but more frequently in irregular interfering aggregations of such forms.

The rider is only suitable for metallurgical purposes in those parts of the veins which have one or both "walls" of limestone.

The *forms* assumed by the ore in the veins are practically two,—(1) as ribs of various and varying breadths, from an inch or two to 18 or 20 feet. These ribs have the same hade as the veins in which they occur, and are found along one or both walls, according to the mineralogical character of these walls. For example, if one be limestone and the other sandstone, due to the throw of the fault by which the vein runs, the workable rider will be along the limestone wall only. If both walls are limestone, and the vein carries lead, there are usually two ribs of rider, one on each wall, the galena being between them; or, again, the rider may extend from "wall to wall," where the vein is not lead-bearing and both walls are limestone, as, for example, the deposit that was worked in the Scar limestone, on the Manor House vein, near Alston Station; (2) as "flats," or irregular beds of ore, projecting several feet from the vein into the different limestones. These flats have usually the same inclination as the limestone in which they occur. In the great limestone, and also in the Scar limestone, there are three levels at which the vein usually flats, known as the upper, middle, and lower flats. The ores are not confined to veins having any particular direction, but occur in all, and in each of the limestones; principally, however, in the Great, Scar, and Tyne-bottom limestones. Where the ores adjoin the limestone, there is a gradual passage from one to the other, *i.e*, from ore to limestone, or *vice versâ*. This feature, and the manner in which the ore of the flats follows the joints in the limestone, may be very clearly seen in the great limestone at Stanhope, near the West-pasture mine.

Years ago, before the nature of the "rider" was understood, or before its value was appreciated, it used to be avoided in the mine; but in recent years much of the ore thus left by the earlier workers has been sent to market. At the Rowantree mine, in Weardale, as much as 6 to 14 feet of ore was, in this way, shot from each side of the vein in the great limestone. Since the value of the ore was recognised, very little has been left in the mine that could be utilised; a rib of hard

"white ore," only 4 to 6 inches wide, with limestone cheeks, was several years ago worked in the Rookhope mine.

These ores do not always occur as the "rider" of lead veins. They are sometimes met with apart from such veins altogether. The direction of a deposit, then, is determined entirely by the joints in the limestone; and the ore is quite free from particles of galena throughout the mass.

CHAPTER VI.

THE ARGILLACEOUS IRONSTONES OF THE CARBONIFEROUS ROCKS.

LITERATURE.

1. *Geological Survey Memoir*, "The Iron Ores of Great Britain":—
   Part I., "Derbyshire and Yorkshire," etc., by W. W. Smyth, 1856.
   Part II., "The Iron Ores of South Staffordshire," by J. Beete Jukes, 1858.
   Part III., "The Iron Ores of South Wales," by E. Rogers, 1861.
   Part IV., "The Iron Ores of the Shropshire Coalfields and of North Staffordshire," by W. W. Smyth, 1862.
2. "The Progress of Coal Mining in the Counties of Derby and Nottingham, etc," by J. T. Woodhouse. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. x.
3. "On Coal and Ironstone Mining in Scotland," by Ralph Moore. *Proceedings of the South Wales Institute of Engineers*, vol. iii., 1861—63.
4. "The Manufacture of Iron in Connection with the Northumberland and Durham Coalfield," by I. Lowthian Bell. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. xiii., 1863—64.
5. "Minerals of the Yorkshire Coalfield," by Benjamin

Holgate. *Proceedings of the Geological and Polytechnic Society of the West Riding of Yorkshire*, vol. vi., 1871—77.
6. "The South Wales Coalfield," by T. Forster Brown. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, 1873—74.
7. *Geological Survey Memoir*, "Geology of the Yorkshire Coalfield," by. A. H. Green, and others. 1878.
8. "The South Wales Clayband Ironstone," by Thomas Joseph. *Proceedings of the South Wales Institute of Engineers*, vol. xii., No. 5.
9. "Stirlingshire Minerals," by Peter M'Beth. *Transactions of the Mining Institute of Scotland*, vol. iii., Part iv.

Thirty-six years ago these rocks yielded four-fifths of the ore raised in Great Britain, but since the introduction of the more cheaply worked ores of the Secondaries, this proportion has been gradually reduced, until now these measures do not produce more than one-sixth of the total ore raised. Not only has there been this great relative fall, but there has been an absolute diminution in the production of clay ironstone to the extent of about 5,000,000 tons per annum. Every year this source of supply becomes less important; the only districts at present raising any considerable quantity being North Staffordshire and Scotland.

The Carboniferous rocks of this country are generally divided as below:—

1. Coal measures.
2. Millstone grit.
3. Carboniferous limestone.

The ironstones under consideration are usually obtained from the first and third of these divisions, which are very differently developed in the various parts of the country where ironstone is worked, as will be seen later, from the details. But there is one very striking change presented by the car-

boniferous limestone series, which may be pointed out now. In South Wales the upper and main part of this formation consists almost entirely of limestone; the lower, or minor part, being made up of shales, sandstones, and thin limestones. The upper beds are usually known as the carboniferous or mountain limestone, the bottom beds as the lower limestone shale. In leaving Glamorganshire the mountain limestone undergoes a change, its upper part being split into several layers by intervening beds of sandstone and shale of various thicknesses. These beds together, *i.e.*, the limestones, sandstones, and shales, make up the formation known as the Yoredale rocks or upper limestone shales. They continue, with the mountain limestone and lower limestone shales, on through North Staffordshire and Lancashire; but as we approach the north of England the mountain limestone becomes split up by beds of sandstone, shale, coal and ironstone, all of which continue to increase northwards, whilst the limestone beds diminish in thickness; so that when we reach Ayrshire and Lanarkshire the mountain limestone, like the Yoredale rocks, is made up almost entirely of sandstones and shales, which include several important seams of coal and beds of ironstone, but only a few thin limestones. This group of rocks is known in Scotland as the lower coal measures to distinguish it from the upper or true coal measures.

Let us now look at some of the more important ironstone districts in detail.

South Wales. The ironstones of this area occur in the coal measures. Those rocks are divided into upper and lower by thick strata of arenaceous rocks sometimes passing into a silicious conglomerate, and known as the "cockshute" or "whiterocks." The lower coal measures, from 450 to 850 feet thick, are the chief repository of the ironstones, and for that reason are often called the "iron-bearing measures," but some ore has been worked in the Pennant grit series of the upper measures. Year by year, however, they are becoming of less importance. In 1872 over 1,100,000 tons were raised, whilst in 1890 the output was but a little over 40,000 tons.

The lower measures extend nearly over the whole field. The iron ores of the east have a higher metallic yield than on the west, but they are thinner. Like the coals, they have had very different names given to them in various parts of the field.

The section below of the lower measures at Dowlais will perhaps be sufficiently illustrative, for present purposes, of the manner in which these ores occur:—

SECTION.

		Ft.	in.	Ft.	in.
Strata				87	0
Coal				0	5
Strata				9	10
Coal				1	3
Black Clod				0	10
Coal				0	2
Strata				52	5
Coal				1	1
Fireclay with BALLS OF IRONSTONE				8	0
Shale				2	0
IRONSTONE				0	3
Black Clod				2	4
Coal				0	2½
Strata				6	0
Shale with IRONSTONE				2	2
SOAP-VEIN	IRONSTONE	0	3		
	Shale	1	6		
	IRONSTONE	0	1½		
	Shale	2	2		
	IRONSTONE	0	1½		
	Coal	1	6½		
	Clod	0	2		
	Coal	0	4	6	2½
Fireclay				6	0
Coal				0	
Clod				0	2

	Ft.	in.
Coal	0	4
Strata	27	3
Coal	1	3
Strata	7	6
IRONSTONE	0	2
Strata	29	9
Coal	1	4
Strata	15	6
IRONSTONE	0	3
Strata	14	1
IRONSTONE	0	4
Shale	18	0
Two courses of IRONSTONE, not regular ...	0	3
Shale	5	0
IRONSTONE	0	2½
Shale	6	0
IRONSTONE	0	1
Shale	0	0½
IRONSTONE	0	1
Strata	5	8
Coal	0	4
Strata	9	0
Shale with IRONSTONE	7	3
LOWER BLACK-PINS { IRONSTONE, Ft. 0, in. 3; Shale ..., Ft. 1, in. 6; **Coal** ..., Ft. 1, in. 1 }	2	10
Strata	76	8
Yard Coal (elled) Monmouthshire	5	11
Strata	33	0
Upper Four-feet Coal	3	2
Strata	50	2
Dowlais Big Coal	13	6
Strata	12	10
Little Coal	1	0
Strata	41	9
IRONSTONE	0	3

		Ft.	in.	Ft.	in.
BLACK-PIN SOAP-VEINS	Shale	0	11		
	IRONSTONE ...	0	1		
	Shale	2	4		
	IRONSTONE ...	0	1		
	Shale	3	10		
	IRONSTONE ...	0	5		
	Shale	3	3		
	IRONSTONE ...	0	1		
	Shale	0	9	11	9
Strata				34	9
BLACKBAND IRONSTONE				0	2
Red Coal				2	0
Shale with two courses of IRONSTONE Balls ...				3	0
Ras Las Coal				11	1½
Strong Shale				9	0
IRONSTONE				0	1½
Shale				1	0
		Ft.	in.		
BRASS-VEIN	IRONSTONE ...	0	2		
	Shale	2	0		
	Coal	2	0		
	Engine Coal ...	0	6	4	
Strata				2	10
		Ft.	in.		
LITTLE-PINS	JACK-PIN IRONSTONE	0	2		
	Shale	3	0		
	LUMPY-VEIN	0	3		
	Shale	2	0		
	DOUBLE-PIN	0	2		
	Shale	0	11		
	STRONG-PIN	0	2		
	Shale	0	10		
	LITTLE-PIN	0	1		
	Shale	0	11		
	LITTLE-PIN	0	1	8	7

		Ft.	in.	Ft.	in.
	Very hard Shale			3	6
	RAS LAS BIG-VEIN IRONSTONE			0	3
	Shale			0	11
	RAS LAS LITTLE-VEIN IRONSTONE			0	2
	Shale			2	6
	Coal and Clay-Vein			1	2
	Strata			7	0
	Three-Coals or Clay-Coals			8	4
	Strata			16	1
	Coal			1	6
	Strata			10	4
	BLUE-VEIN IRONSTONE			0	4
	Very hard Shale			7	0
	LITTLE-VEIN IRONSTONE			0	5
	Little-Vein			5	6
	Strata			7	9
	Coal			1	6
	Strata			3	9
	Coal			1	3
	Strata			8	0
BLUE ABOVE VEIN	IRONSTONE	0	5		
	Shale	3	7		
	IRONSTONE	0	2		
	Shale	1	0		
	IRONSTONE	0	1½	5	3½
	Shale			4	8
	Lower four feet or old Coal			13	6
	Strata			7	7
SPOTTED-VEIN	SPOTTED-PIN IRONSTONE	0	4		
	Shale	1	6		
	PIN BRYTH	0	3		
	Shale	3	2		
	RIDER BALLS	0	5	5	8

		Ft.	in.	Ft.	in.
Strata ...				13	3
YELLOW-VEIN	Shale	1	8		
	MIDDLE-PIN ...	0	2		
	Shale	2	10		
	DOUBLE-PIN ...	0	4	5	0
Strata ...				3	2
RED-VEIN	RED-VEIN PIN ...	0	2		
	Strata	1	6		
	LITTLE-PIN ...	0	1½		
	Shale	1	6		
	RED-VEIN	0	4		
	Shale	3	9		
	BLACK-VEIN ...	0	4	7	8½
Strata ...				14	0
LITTLE BLUE-VEIN	LITTLE BLUE-VEIN	0	3		
	Shale	2	0		
	SPOTTED PIN ...	0	2		
	Shale	3	8		
	YELLOW BALLS ...	0	2		
	Strata	7	5		
	IRONSTONE ...	0	2		
	Shale	1	10		
	JENKIN-VEIN ...	0	2		
	Shale	0	6		
	JENKIN-VEIN ...	0	2		
	Shale	2	6	19	0
JENKIN-PINS	TOBACCO-PIN ...	0	1½		
	Shale	1	2		
	SMOOTH-PIN	0	0¾		
	Shale	0	6		
	WATCH-PIN	0	0½		
	Shale	1	1		
	DOUBLE-PIN	0	1¼		
	Shale	0	4		
	DOUBLE-PIN	0	0½	3	5½

		Ft.	in.	Ft.	in.
Shale				3	0
LUMPY-VEIN	LUMPY-VEIN	0	1½		
	Shale	0	10		
	LUMPY-VEIN	0	2		
	Shale	2	10		
	ROUGH-PIN	0	3	4	2½
Shale				1	8
Coal				1	3
Strata				10	3
IRONSTONE				0	5
Shale				6	0
IRONSTONE				0	1½
Shale				1	2
IRONSTONE				0	1
Shale				2	3
IRONSTONE				0	1
Shale				0	11
IRONSTONE				0	1½
Shale				2	3
IRONSTONE				0	1½
Shale				0	9
IRONSTONE				0	1
Shale				3	3
IRONSTONE				0	1½
Shale				3	9
IRONSTONE				0	1½
Shale				1	11
IRONSTONE				0	2½
Shale				1	10
BOTTOM ROSSER-VEIN				0	4
Strata				9	6
IRONSTONE				0	3
Blackshale				0	5
IRONSTONE				0	3
Blackshale				0	10

		Ft.	in.
	IRONSTONE	0	2
	Blackshale	5	5
	IRONSTONE	0	2
	Blackshale	4	6
	Black silicious sandstone	1	2
	Blackshale	0	9
Millstone Grit.	Upper stratum of Farewell Rock, light grey sandstone	46	9
	Black clay, with layers of coal	1	3
	Strata	17	6

The local, lithological, and stratigraphical names employed in the section may be translated as under:—

Pin = nodule.
Vein = seam, or several seams together.
Clod = tough shaly clay.

The ironstones occur either in thin beds or as nodules, in shale or clay. They vary in colour from light grey, through brown to black. They are frequently seamed in an irregular manner with dolomite, calcite, or quartz. These minerals appear to occupy the place of pre-existing cavities. Sometimes the cavities are not quite filled, their walls being simply lined with crystals of calcite, pyrite, dolomite, or quartz. Hatchetine and Millerite are frequently met with in these cavities, and sometimes a trace of copper.

The chemical composition of these ironstones is approximately indicated by the table of analyses on the next page, by Mr. E. Riley, of five different ores from the Dowlais district.

The ironstones of which Nos. 1 and 3 are analyses occur in nodules, those of 2, 4, and 5, in thin beds.

The ironstones from other parts of the field yield practically similar results. Taken over the whole field the ores may be said to vary in the quantity of iron they contain from about 21 to 39, with an average of 31 per cent.; the non-metallic minerals in them, as in all other iron ores, being in inverse proportion, and increasing much more rapidly than the iron diminishes,

Constituents.	1 Rosser-Vein Mine.	2 Little Blue-Vein.	3 Lumpy-Vein.	4 Gwr Hyd.	5 Black-Band.
Peroxide of iron ...	·41	·40	·41	—	—
Protoxide of iron ...	41·03	38·77	44·29	39·00	48·76
„ „ manganese	·55	1·30	1·13	·50	1·21
Silica	13·35	13·55	7·91 }	25·33	1·21
Alumina	5·79	3·28	4·20 }		
Lime	3·00	4·54	3·18	2·75	1·69
Magnesia	3·36	4·40	3·92	2·41	2·61
Potash	·86	·87	·74	—	—
Phosphoric acid ...	·70	·46	·42	1·28	·58
Sulphur	—	·01	·03	—	·03
Bi-sulphide of iron ...	—	—	—	—	·07
Carbonic acid	28·49	30·53	32·48	26·14	33·09
Water, combined ...	1·36	1·08	1·03	1·60	—
„ hygroscopic ...	·57	·35	·42	·79	·25
Organic matter ...	·07	·29	·35	—	11·08
Total	99·54	99·83	100·51	99·80	100·58
Metallic iron	32·18	30·43	34·72	30·33	37·8
Specific gravity ...	3.29	3·15	3·27	3·15	2·57

as shown in the following particulars from analyses of (No. 1) the Black-pin mine (Middlepin), Pontypool, and (No. 2) the Black-vein (Red-vein measures) Cwm Celyn.

	Iron.	Silica.	Alumina.	Lime.	Magnesia.
No. 1 ...	20·95	18·56	8·67	8·14	5·48
No. 2 ...	38·75	4·60	5·60	2·60	1·38

The ores before being sent to the furnaces are roasted. The loss of weight, in this process, ranges from 21 to 31 per cent., the richest ores losing most.

The following list of fossils from these ironstones and their associated shales was prepared some years ago by Mr. J. W. Salter:[1]—

I.—*Rosser-Veins* (*wholly marine*).

Spirifer Urii, Flem.
„ glaber, Sow.

[1] *Geological Survey Memoir*, "The Iron Ores of Great Britain," Part 3.

Spirifer bisulcatus, Sow.
Orthis Michelini, Lev.
„ resupinata, Sow.
Streptorhynchus crenistria (Orthis crenistria, Phillips).
Chonetes Hardrensis, Ph.
Productus semireticulatus, Martin (P. antiquatus and P. Martini, Sowerby).
Productus hemispherica, Sow. (P. Cora D'Orb).
Discina nitida, Phill.
Lingula mytiloides, Sow.
Aviculopecten gentilis, Sow.
„ scalaris, Sow.
Myalina triangularis, Sow.
Arca (striate sp.).
Myacites (sp.).
Schizodus sulcatus.
„ carbonarius.
Ctenodonta undulata, Ph.
„ gibbosa, Flem.
„ æqualis, Sow.
Edmondia unioniformis, Ph.
Myacites sulcata, Flem.
Pleurotomaria limbata Ph.
Macrocheilus (minute).
Litorina ? obscura, Sow.
Conularia quadrisulcata, Sow.
Bellerophon apertus, Sow.
„ decussatus, Flem.
„ hiulcus, Sow.
Discites falcatus, Sow.
Nautilus concavus, Sow.
Goniatites Listeri, Sow.
Orthoceras.
Encrinite stems.
Megalichthys Hibberti, Ag., and one or two other fish fragments.

II.—*Bottom-Vein* (*Marine*).

Rhizodus granulatus, Ag. teeth,—large and small.
Pleuracanthus gibbosus, teeth (Diplodus Ag.).
Byssacanthus (?).
Palæoniscus, Sp.
Amblypterus (fluted throat plates) Agass.
Megalichthys Hibberti.
Helodus simplex, Ag.
Pæcilodus angustus, Ag.

III.—*Blue-Vein or Big-Vein* (*Marine*).

Myalina carinata, Sow.
Anthracosia acuta.
„ (ovalis or centralis).
Spirorbis carbonarius.

IV.—*Red-Vein* (*Brackish Water or Marine*).

Anthracosia acuta, Sow.
„ ovalis, Martin.
Modiola, small convex species.
Edmondia (?), a shell like a Cyprina.

V.—*Spotted-Vein* (*probably Marine*).

Spirorbis Carbonarius, Murch.
Track of a crustacean (Limulus ?) 6 feet under the "spotted-vein."

VI.—*Old Coal—Black Band* (*Marine* [?]).

Anthracosia acuta, Sow.
„ ovalis, Mart.
Rhizodus granulatus, Ag.

VII.—*Mine over "Engine Coal"* (*Marine*).

Spirifer bisulcatus, Sow.
Productus scabriculus, Sow.
Neuropteris Loshii, Brong.

VIII.—*Darran-Pins* (*Marine or Brackish*).

Anthracomya senex, n. sp.
„ modiolaris, Sow.
Myalina modiolaris.
„ quadrata, Sow.
„ carinata, Sow.
Anthracosia aquilina, Sow.
„ ovalis (?), (or centralis).
„ thick squarish, sp.
„ lateralis, Brown (var. of A, acuta [?]).

IX.—*Mine—Will-Shone or Pin Will-Shone—over Bydyllog or Ras Las Coal* (*Marine*).

Athyris planosulcata, Sow.

X.—*Mine over Three-quarter Coal* (*Marine*).

Anthracomya (new genus), pumila, n. sp.
„ subcentralis, n. sp.

XI.—*Mine under Big-Vein Coal* (*Marine* [?]).

Anthracosia centralis (?) (an oval species smaller than S. ovalis).

XII.—*Ell-Balls, above Elled-Coal.*

Asterophyllites grandis, Lindl.
Lepidodendron selaginoides.
„ Sternbergii, Brong.
Ulodendron minus, Lindl.
Neuropteris gigantea, Sternb.
Sphenopteris Höninghausii.
Alethopteris heterophylla.
Pecopteris oreopteridis, Brong.
„ abbreviata, Brong.

XIII.—*Black-Pins Mine* (*Brackish or Marine* [?]).

Dadoxylon (Sternbergia) approximatum, Lindl.
Knorria Sellonii, Sternb.
„ sp.
Halonia tortuosa, Lindl.
Anthrocosia acuta, Sow.

XIV.—*Soap-Vein Mine* (*Marine*).

Worn burrows, abundant.
Anthracomya Adamsii, n. sp.
Neuropteris Voltzii, Bróng. vár (?).
Sphenopteris Höninghausii.

XV.—*Black-Band* (*Marine*).

Modiola (or Anthracomya), small species.
Megalichthys Hibberti, Ag.
Rhizodus granulatus, Ag, the small intermediate teeth.

"*Penny Pieces.*"

Anthracosia aquilina, Sow.
„ ovalis, Martin.
„ centralis (?) Sow.
„ sp. with keeled ridges.

Shropshire. (Coalbrook Dale.) Here, too, there has been a great fall in the quantity of ore raised, the present output only being about one-tenth of what it was twenty years ago.

The ironstones occur in the coal measures, which have a maximum thickness of about 1,000 feet. They are usually divided into upper and lower, the former resting on a severely denuded surface of the latter, in such a way that the upper coals and ironstone of the lower measures, even down to the pennystone, are wanting altogether in certain areas notwithstanding that the upper measures are present. The upper beds of the lower measures are confined to the northern part

of the field; but as the depth of any bed in the measures increases it has a more southern extension, the pennystone and the measures below it occurring throughout the field.

The principal ironstones occur in the lower measures. A section of these rocks is given below:—

		Ft.	in.
LOWER COAL MEASURES.	**Chance Coal**	0	9
	Strata	149	6
	TOP PENNY MEASURE (sometimes called chance Pennystone), Ironstone nodules in dark grey clay ... ... 3ft. to	8	0
	Strata	37	6
	Fungous-Coal	3	0
	Strata	4	0
	Foot-Coal	1	0
	BLACKSTONE MEASURE (Ironstone nodules in dark grey clay) ... ... 3ft. 6in. to	4	0
	Stone-Coal	4	0
	Strata	3	0
	Gur Coal	2	0
	Strata	8	0
	BRICK-MEASURE (Ironstone nodules in grey clay) ... ... 7ft. to	16	0
	Strata	13	0
	BALLSTONE (Ironstone in grey clay) ... 6ft. to	13	0
	Strata	6	4
	Top Coal	5	0
	Strata	5	0
	Three-quarter Coal	2	0
	Strata	6	0
	Double Coal	6	0
	Strata	1	6
	YELLOWSTONE MEASURE (Ironstone in grey clay) ... ... 2ft. to	9	0
	Yard Coal	3	0
	Strata	1	6

		Ft.	in.
Lower Coal Measures.	BLUE FLAT (Brownish Ironstone in clay) ...	6	0
	Strata	5	0
	WHITE FLAT (Ironstone in grey clay)... ...	4	0
	Strata	23	0
	Flint Coal	5	0
	Strata	21	0
	PENNY MEASURE or bottom Pennystone (Ironstone in dark grey clay) ... ... 6ft. to	31	0
	Sulphur Coal	5	0
	Strata	1	6
	Upper Church Coal	0	10
	Strata	3	0
	Church Coal	2	0
	Strata	6	0
	Two-foot Coal	2	0
	Strata	12	0
	Best Coal	2	0
	Randle Coal	3	0
	Strata	2	0
	Clod Coal	4	0
	Strata	13	6
	Little-flint Coal	2	0
	Strata	10	0
	CRAWSTONE MEASURE ... ... 2 ft. to	3	0
	Coal under ditto	1	0
	Strata	5	7
	Lancashire Ladies' Coal	0	9
	Strata	40	0
	WENLOCK LIMESTONE (Silurian)	—	

All the ironstones mentioned in this section (except the three-inch bed in the top of the bottom pennystone) occur either as nodules or tabular masses, and excepting the crawstone, they are all embedded in shale. The latter ore occurs in finely granular sandstone. The yield per acre of the different measures is as below :—

	Tons.	Thickness taken. Feet.
Chance pennystone	800	6
Blackstone	1800	4
Brick measure	1500	16
Ballstone	1300	9
Yellowstone	1200	9
Blue-flats	1500	6
White-flats	1300	6
Pennystone	2600	24

The composition of the ironstones, as determined by J. Spiller, is set forth in the subjoined table:—

Constituents.	Black-stone.	Blue-flats.	White-flats.	Penny-stone.	Craw-stone.
Peroxide of iron ...	·53	·69	1·62	·81	·43
Protoxide „ „ ...	48·28	46·30	44·33	45·08	51·45
„ „ manganese	·82	·82	1·00	1·69	·54
Silica	7·36	8·23	9·90	6·23	6·83
Alumina	4·17	4·26	4·52	2·39	2·85
Lime	2·34	2·30	2·98	3·11	2·13
Magnesia	1·83	2·08	1·97	4·20	·42
Potash	·10	·33	·24	trace	·16
Carbonic acid	32·98	31·68	30·92	34·04	33·31
Phosphoric acid ...	·26	·50	·70	·46	·23
Sulphuric acid ...	·10	·11	·06	trace	—
Bilsulphide of iron ...	·19	·08	·01	·48	·02
Water combined ...	·62	·81	·95	·72	·54
„ hygroscopic ...	·24	·28	·35	·30	·19
Organic matter ...	·62	·62	·38	·23	·67
Total	100·44	99·09	99·93	99·74	99·77
Metallic iron	37·92	36·49	35·61	35·63	40·27
Specific gravity ...	3·57	3·5	3·5	3·5	3·68

The specific gravity of the brick-measure ironstone is 3·3 and of the ballstone 3·4.

These ironstones are much less variable, in the proportions of their mineral contents, than those of South Wales, and have a higher metallic yield, the average being about 37 per cent. The irregular cavities within the nodules contain one or more of the following minerals; clay, blende, pyrite, barite, calcite, and traces of lead and copper.

Organic remains in great variety are preserved in the nodules and accompanying shales, as shown in the following table chiefly after Salter:—

Chance Pennystone.

Productus scabriculus, Sow.
Conularia quadrisulcata, Sow.
Fish, etc.

Blackstone.

Stigmaria, Lingulæ, Fish.

Ballstone.

Lepidodendron selaginoides, Sternb.
„ Sternbergii, Brong.
Neuropteris gigantea, Sternb.
Pecopteris oreopteridis, Brong.
„ abbreviata, Brong.

Yellowstone and Blue-Flats.

Anthracosia aquilina, Sow.

White-Flats.

Anthracosia aquilina, Sow.
Myalina modiolaris.
„ quadrata, Sow.
Teeth and spines of megalichthys and cyracanthus.
Spines of limulus.
Plant remains.

Pennystone.

Spirifer bisulcata, Sow.
Lingula mytiloides, Sow.
Productus scabriculus, Sow.
Discina nitida.
Anthracosia subconstricta.
„ robusta, Sow.

Anthracosla aquilina.
„ acuta.
Anthracomya.
Myacites.
Anthracoptera quadrata, Sow. Numerous examples of.
Axinus carbonarius, Porth.
„ æqualis, Sow.
„ sulcatus, Sow.
Ctenodonta aqualis.
Myalina quadrata.
Aviculopecten gentilis, Sow.
„ scalaris, Sow.
Conularia quadrisulcata, Sow.
Natica pleurotomaria.
Bellerophon hiulcus, Sow.
Goniatites.
Orthoceras.
Nautilus concavus, Sow.
Megalichthys Hibberti, Ag.

Crawstone.

Myalina triangularis, Sow.
Myalina carinata, Sow.
Anthracomya modiolaris, Sow.

South Staffordshire. The output has diminished here from 715,451 tons in 1875 to 41,063 in 1890.

The middle coal measures rest on the upper Silurians—the Devonians, carboniferous limestone, millstone grit and lower coal measures being absent. The thickness of the measures is about 1,300 feet in the maximum, but the ironstones all occur in the lower 500 feet. A general section of these latter rocks is given below :—

SECTION.

		Ft.
Middle Coal Measures.	**Brooch Coal** ... ... about	4
	BROOCH-BINDS IRONSTONE measures	5 to 20

Middle Coal Measures.

	Ft.	Ft.
Herring Coal (South of Dudley) ...		1
PINS AND PENNYEARTH IRONSTONE measures	6 to	31
Strata	38 „	157
TEN FOOT AND BACKSTONE IRONSTONE measures (in the Pensnett District)	6 „	14
Thick Coal		30
[1] GRAINS AND WHITERY IRONSTONES (occasional)	2 „	8
GUBBIN IRONSTONE measures, sometimes called the Little or Top or Thick Coal Gubbin, sometimes the Black Ironstone (about 15 in. of Ironstone in dark shale)	2 „	9
Strata	2 „	28
Heathen Coal (1½ to 10 feet) ...	about	3
Strata	0 to	43
Rubble or Lower Heathen Coal ...	2 „	4
Strata containing, at Bentley, Ironstones known as the Lambstone and Brownstone	10 „	33
NEW MINE OR WHITE IRONSTONE 6 to 21 in. of Ironstone in grey clay	2 „	10
"PENNYSTONE" Measures, called also "Bluestone" or "Cakes" ...	10 „	25
Sulphur Coal	2 „	9
Strata	2 „	99
New Mine Coal	2 „	11
"FIRECLAY BALLS" IRONSTONE measures (occasional)	2 „	39
Fireclay Coal	1 „	14
Strata	2 „	10
"GETTING ROCK" IRONSTONE (occasional)	4 „	5

[1] In these measures near Bentley an ironstone, called the Bind, is worked.

MIDDLE COAL MEASURES.		Ft.		Ft.
	POOR ROBIN IRONSTONE measures	3	„	4
	Strata	0	„	9
	"ROUGH HILLS" WHITE IRONSTONE (occasional)	2	„	19
	Bottom Coal	3	„	12
	Strata	5	„	30
	"GUBBIN AND BALLS" IRONSTONE (sometimes called bottom or great Gubbin), 20 to 25 in. of Ironstone in dark clay	0	„	10
	Strata	18	„	50
	Singing or Mealy Grey coal ...	2	„	4
	Strata	16	„	50
	"BLUE FLATS" IRONSTONE, 5 to 16 in. of Ironstone in grey shale ...	2	„	9
	Strata	10	„	14
	"SILVER THREADS" IRONSTONE ...	4	„	7
	Strata	6	„	15
	DIAMONDS IRONSTONE	2	„	4
	Strata	0	„	50

LUDLOW ROCKS (upper Silurian).

The mean thickness of the measures, between the thick coal and the Blue-flats ironstone, over a large area north-west of Dudley is put, by Jukes, at 320 feet.

The ironstones occur in layers of nodules or tabular masses, in shale, as partly illustrated in the sections hereunder :—

Gubbin Ironstone at Upper Gornal (after Kenyon Blackwell).

	Ft.	in.	Ft.	in.
IRONSTONE	0	6		
Dark clunch			2	0
IRONSTONE (called Cannock) ...	0	6		
Dark clunch			2	0
IRONSTONE (called rubble) ...	0	3		
Blackbatt				6
	1	3	4	6

New-Mine Ironstone.

IRONSTONE	0	3		
Clunch			0	7
IRONSTONE	0	4		
Clunch			3	3
IRONSTONE		4		
	0	11	3	10

Gubbin and Balls Ironstone.

BALLS OF IRONSTONE ...	0	8		
Clod			2	6
BALLS OF IRONSTONE ...	0	6		
Dark Clod			1	6
GUBBIN IRONSTONE	0	6		
Clod			1	0
GUBBIN IRONSTONE	0	3		
	1	11	5	0

Blue-Flats Ironstone.

TOPSTONE	0	6		
Binds, etc.			2	0
SECOND-STONE	0	3		
Parting			1	3
THIRD-STONE	0	4		
Ground with Chitterstone ...			4	2
BOTTOM-STONE	0	3		
	1	4	7	5

Local names used in these sections.

Clunch = tough clay, sometimes sandy.
Bind = shale, clayey.
Clod = shale, earthy.
Batt = carbonaceous shale.

The yield per acre of the more important measures is given in the following table:—

	Tons.
Gubbin	1,200
Whitestone	1,700
Poor Robin	1,200
Rough-hills whitestone	2,400
Gubbin and Balls	2,400
Blue-flats	2,400

The chemical composition of the Ironstones has been determined by the analyses of Messrs. A. Dick and C. Tookey (see next page).

The specific gravity of these ores varies from 2·93 to 3·69. The cracks in the nodules contain, in varying quantities, one or more of the following minerals: clay, blende, galena, chalcopyrite, pyrite, calcite and dolomite.

Some of the Ironstones contain organic remains. In the upper part of the cakes, and the bottom of the whitestone, there have been found *anthracosia*, *producta scabricula*, *avicula quadrata*, *lingula mytiloides?* *orbicula nitida*, *conularia quadrisulcata*.

North Staffordshire. This, at the present time, is the most important area in the country for the production of clay carbonates, as will be seen on reference to the statistics in Part I. The coal measures have a maximum thickness of about 6,000 feet, but most of the workable ironstones are found above the middle of the series, ranging from about 1,000 feet to about 2,400 feet below the top.

The following section of the ore-bearing rocks passed through at Silverdale gives the horizon of the principal ironstones.

Local Names.

Mine = ironstone.
Bass = shale (carbonaceous).
Bind = „

Constituents.	Brooch.	Pins.*	Grains.*	Gub-bin.*	White-stone.	Blue-stone.*	Fire-clay Balls.	Poor Ro-bins.*	Rough Hill White-stone.	Gubbin and Balls.*	Blue Flats.	Silver Threads	Dia-monds.
Peroxide of iron ...	·39	·54	—	·13	1·15	·84	·57	·53	—	3·75	1·58	2·75	3·05
Protoxide of iron ...	43·81	45·35	54·12	46·30	30·96	43·55	46·39	49·61	44·20	49·04	42·34	40·39	40·01
„ „ manganese	·98	·56	2·05	1·44	·73	1·65	1·01	·98	2·43	·79	1·12	·75	·75
Silica	12·86	10·63	2·11	10·29	26·50	7·81	11·71	6·26	18·39	7·94	11·17	6·74	13·72
Alumina	6·16	5·70	·78	4·80	9·58	3·70	6·58	2·85		3·76	4·24	3·27	4·68
Lime	1·67	2·60	2·21	·76	1·84	1·72	1·12	1·89	·96	·79	3·89	7·34	2·66
Magnesia	1·15	1·26	·62	·94	3·11	4·74	1·33	1·86	1·04	·66	1·48	2·22	2·84
Potash	·42	·36	trace	—	·74	—	·28	·39	—	·32	·84	·26	·18
Carbonic acid	28·22	30·21	35·25	30·44	22·13	34·00	30·00	33·05	29·03	30·80	30·91	33·35	29·13
Phosphoric acid ...	·83	·46	·69	·74	·26	·15	·11	·34	·66	·18	·25	·22	·21
Sulphuric acid ...	trace	trace	trace	trace	trace	·06	·10	·10	·05	—	trace	—	—
Bilsulphide of iron ...	·30	·20	·40	·07	·12	·47	·17	·17	·26	·13	·06	·11	·06
Water combined ...	1·32	1·64	1·07	1·38	1·83	·64	1·50	1·30	—	·77	·73	·60	·72
„ hygroscopic ...	·54				·56					·26	·28	·33	·39
Organic matter ...	·88	1·59	1·36	1·14	·10	—	·21	1·24	2·68	·60	·56	·80	1·06
Total	99·53	101·10	100·66	98·43	99·61	99·33	101·08	100·57	99·70	99·79	99·45	99·13	99·46
Metallic iron	34·35	35·74	42·26	36·14	24·88	34·88	36·56	39·02	34·53	40·81	34·41	33·44	33·28

* Dried at 212° Fahr.

Average metallic yield about 35 per cent.

			Ft.	in.
UPPER COAL MEASURES.	TOP-RED MINE		1	6
	Strata		105	0
	BLACK BAND		3	0
	Coal		2	9
	Strata		30	0
	RED-SHAG IRONSTONE		0 to 5	0
	Coal		2	0
	Strata		42	0
	RED MINE (LOWER) average thickness 14 in.		0 ,, 9	0
	Coal		2	0
	Strata, containing Bassy Mine at Lane End ...		150	0
MIDDLE COAL MEASURES.	**Peacock Coal**		2	6
	Strata		75	0
	Spencroft Coal, average		5	6
	Strata		57	0
	Great-row Coal, sometimes in two bands with cannel		8	0
	Strata		54	0
	CANNEL MINE (Wood's Mine)		6	6
	Strata		27	0
	GUBBIN IRONSTONE		1	2
	Strata		30	0
	BLUE-FLATS in bands ...	Position of Deep Mine measures at Lane End.	0	10
	SHEATH MINE (0 to 12 in.)		1	0
	BLACKSTONE, in 4 bands		0	10
	Coal (Deep Mine in the Potteries)		0	6
	Strata		42	0
	RUSTY MINE in 4 bands, 6 in. to		0	8
	Strata		54	0
	CHALKY MINE 2 to 2½ ft. Ironstone, 8 to 11 bands, ...		18	0
	Strata, containing Little Mine at Apedale ...		36	0
	NEW MINE STONE 7 bands, 10 in. in ...		6	0
	Strata		48	0
	Winghay or Knowles Coal		5	6
	BROWN STONE, in bands and balls 33 in. in		9	0

		Ft.	in.
MIDDLE COAL MEASURES.	Strata	72	0
	TOP THICK-BAND in two beds	0	8
	Middle Thick-band Coal	1	3
	IRONSTONE, two bands, 7 in. in	4	0
	Bind	42	0
	GOLD MINE IRONSTONE 24 in. in	9	0
	Strata	75	0
	Rowhurst Coal, 7 ft. in two bands	7	0
	Clunch	9	0
	Lower Coal (Bingay in Potteries)	3	0
	Strata	45	0
	IRONSTONE	0	6
	Coal, Burnwood (12 to 28 in. on eastern side of field)	0	6
	Strata	27	0
	IRONSTONE, two bands	0	6
	Coal, twist	3	3
	Strata	120	0
	Four-foot Coal (Moss in Potteries)	4	6
	Strata	24	0
	Two-foot Coal	1	6
	Strata	36	0
	Single five-foot Coal (4 ft. at Kidsgrove) ...	5	0
	Strata	75	0
	Ragman Coal	3	6
	Strata	12	0
	Rough seven-foot Coal	7	0
	Strata	30	0
	Hams Coal	4 ft. to 5	0
	Strata	90	0
	Stony eight-foot Coal	1	6
	Strata	180	0
	Ten-foot Coal	7	6
	Strata	60	0
	IRONSTONE two bands	0	6
	Top, Two-row Coal	2	3

		Ft.	in.
Middle Coal Measures.	Strata	30	0
	Bottom, Two-row Coal	2	3
	Strata	30	0
	Clod Coal in two bands	2	3
	Strata	30	0
	Bowling-alley Coal	1	4
	Strata, shaly	132	0
	Rock or strong sandstone	60	0
	Shale	3	0
	Coal, seven-foot Nabbs	5	6
	Strata	21	0
	Rider Coal	0	6
	Strong ground	90	0
	Coal, eight-foot Nabbs	5	0
	Strata with three little coals of 15 in. each, 45 ft. apart	195	0
	Coal, Bullhurst ... ... 3 ft. to	6	0
	Strata	60	0
	Coal, Winpenny	2	2
	Lower Coal Measures	900	0
	Millstone Grit		

These ironstones are mostly in bands or thin beds, the Cannel mine, Gubbin, and Pennystone being the only important ores that are nodular. The beds, especially the blackbands, when seen in section, have mostly an irregular striped appearance ; the lines being parallel to the bedding.

The ironstones above the Peacock coal are all blackbands, and occur immediately on the top of coal seams. They are the Red-shag, Gutter and Bassy of Shelton, the Top-red mine, Blackband, Red-shag and Red mine of Silverdale and the Bassy mine of Lane End and Great Fenton. Like blackbands generally, they contain thin laminæ of dark carbonaceous matter, the intervening ironstone being of a brownish colour. The thickness of these stones, as a rule, varies inversely to that of the underlying coal. That is to say, when the ironstones

are thickest the coals are thinnest, and *vice versâ*. To distinguish the different qualities of the stones they are sometimes divided into "tops," "middles," and "bottoms," the first being the poorest and the last the richest.

These upper ironstones and their accompanying coals appear to be of very limited extent on any given horizon; for, taking the three localities named above, the same seam probably does not occur in any two of them, if we except the Bassy mine of Shelton and Lane End.

The ores below the Peacock coal are clay ironstones, and occur either as nodules or thin bands separated by shales; in some places being in association with coal seams, at others quite apart from them. A few sections will show their mode of occurrence:—

Woods Mine Measures (at Lane End).

	In.	Ft.	in.
Bass		3	0
IRONSTONE	3		
Bass		2	0
IRONSTONE	2		
Bass		2	0
IRONSTONE	2		
Bass		2	0
IRONSTONE	2		
Total	9	9	0

Deep Mine Measures (at Lane End).

	Ft.	in.	Ft.	in.
TOP IRONSTONE		6		
Bass			1	6
SECOND IRONSTONE		3		
Bass			1	6
THIRD IRONSTONE		2		
Bass			1	3
FOURTH IRONSTONE		4		
Coal				
Total	1	3	4	3

Chalky Mine Measures (at Lane End).

	In.	Ft.	in.
FIRST IRONSTONE	3		
Bass		2	3
SECOND IRONSTONE	2		
Bass		1	9
THIRD IRONSTONE	7		
Coal			
Total	12	4	0

The production per acre of the ores is given in the following table:—

	Tons.
Bassy Mine	5000
Cannel Mine	4200
Blackstone	1900
Sheath	2100
Chalky	2900
Little	2400
Brown	2900

The chemical constitution of these ores has been determined by Mr. A. B. Dick as shown in the table on next page.

Numbers 1, 2, and 3 are blackbands, and, as is usual, they contain very much less argillaceous matter than the claybands. The average specific gravity of the blackbands is about 2·4. Owing to the refractory nature of these ores, they are only used in the local furnaces to the extent of 50% of the ore burden, 45% being the more expensively obtained claybands of different kinds, and 5% the silicious ore of the Lower Oolite of Northampton. Average metallic yield of claybands 37, of the blackbands 38 per cent.

The ores frequently contain thin veins of calcite. Crystals of blende occur in the cavities of some of them, and traces of lead and copper are occasionally found.

Constituents.	1* Red Shag, at Shelton	2* Red Mine of Silverdale.	3* Bassy Mine, called Red Mine, at Shelton	4 Cannel Mine of Apedale.	5* Pennystone of Shelton	6* Deep Mine, Lane End.	7* Chalky Mine, Lane End.
Peroxide of iron ...	·05	1·01	5·06	·20	3·11	·21	·12
Protoxide of iron ...	46·53	34·22	45·53	41·80	46·35	48·33	51·07
„ „ manganese	2·54	2·87	1·74	2·16	1·61	2·99	2·36
Silica	1·93	3·13	1·36	7·32	5·78	6·25	3·02
Alumina	1·22	1·35	·74	3·81	1·52	2·83	2·47
Lime	2·44	11·91	2·91	5·11	1·93	1·52	1·74
Magnesia	1·39	1·44	2·13	3·03	2·24	1·19	1·10
Potash	·20	trace	·05	·09	·18	·22	·28
Carbonic acid	30·77	32·52	32·12	32·40	32·46	32·76	33·63
Phosphoric acid ...	·69	·87	·86	1·40	·67	·87	1·12
Sulphuric acid ...	·04	·12	·08	trace	trace	trace	trace
Bisulphide of iron ...	·34	·35	·37	·04	·15	·19	·17
Water combined ...	} 1·47	·75	} 2·29	·71	} 1·43	·85	·99
„ hygroscopic ...		·23		·36			
Organic matter ...	10·47	8·93	5·20	·79	2·95	1·17	1·24
Total	100·08	99·70	100·44	99·22	100·38	99·38	99·31
Metallic iron	36·39	27·33	39·13	32·64	38·29	37·83	39·88
Specific gravity ...	2·25	2·09	2·34	3·12	3·06	3·25	3·57

* Dried at 212° Fahr.

Mr. J. W. Salter has met with the following organic remains in these ironstones and their associated shales :—

Red Shag.

Anthracomya Phillipsii, Willmsn.

Blackband.

Anthracomya Phillipsii, Willmsn.

Red Mine and Coal.

Anthracomya Phillipsii, Willmsn.

Bassy Mine.

Stigmaria, large.
Cytheropsis.

Spirorbis carbonarius, Murch.
Anthracomya Phillipsii, Willmsn.
Diplodus gibbosus, Ag.

Gubbin Ironstone Shale.

Anthracomya Phillipsii, Willmsn.
A. sp.
Anthracoptera quadrata, Sow.
A. sp.
Anthracosia robusta, Sow.
A. subconstricta, Sow.
A. lateralis, Brown.
Cytheropsis.
Megalichthys Hibberti, Ag.
Platysomus.
Palæoniscus.
Diplodus gibbosus, Ag.
Ctenacanthus Hybodoides, Eg.
Pleuracanthus (a flat lancet-shaped tooth).

Cannel Mine.

Cytheropsis.
Sanguinolites.

Woods Mine Bass.

Calamites undulatus, Brong.
Palæoniscus, scales.
Megalichthys Hibberti, Ag.
Diplodus gibbosus, Ag.
D. minutus, Ag.
Gyracanthus formosus, Ag. (Lancet-shaped tooth.)

Deep Mine Ironstone.

Neuropteris cordata, Brong.
N. sp. with serrated edges.
Cytheropsis.
Megalichthys Hibberti, Ag.

Rhizodus.
Palæoniscus, 4 or 5 sp. (new).
Platysomus 2 sp. (1 new).
Gyrolepis.
Ctenacanthus.
Cœlacanthus, 2 species.
Holoptychius (large scales).
Gyracanthus formosus, Ag.
Diplodus gibbosus, Ag.
D. minutus, Ag.
Ctenopthychius apicalis, Ag.
C. denticulatus, Ag.
C. pectinatus, Ag.
Helodus simplex, Ag.
Pleuracanthus lævissimus, Ag.

Chalky Mine Ironstone Shale.

Anthracomya Phillipsii, Willmsn.
Megalichthys Hibberti, Ag.
Diplodus gibbosus, Ag.
D. minutus? Ag.
Gyrolepis.

New Mine Ironstone Bass.

Sigillaria.
Anthracomya Adamsii, Salter.
Anthracosia robusta, Sow.
A. sp.
Anthracoptera.
Megalichthys Hibberti, Ag.
Rhizodus.
Palæoniscus, scales.
Platysomus.
Gyracanthus formosus, Ag.
Orthacanthus cylindricus, Ag.
Pleuracanthus (Diplodus).
Gibbosus, Ag.

Rag Mine Ironstone Shale above Knowles Coal.

Ulodendron minus, Lindl.
Lepidodendron obovatum, Sternb.
Sigillaria.
Calamites cannæformis, Schl.
Neuropteris heterophylla, Brong.
Anthracosia subconstricta, Sow.
Megalichthys Hibberti, Ag.
Holoptychius.
Rhizodus (large scale).
Palæoniscus, scales.
Gyrolepis, sp.
Platysomus, 2 var.
Cœlacanthus.
Ctenoptychius apicalis, Ag.
C. denticulatus, Ag.
C. pectinatus, Ag.
Petalodus.
Archodus.
Helodus simplex, Ag.
Cladodus.
Orthacanthus cylindricus, Ag.
Gyracanthus formosus, Ag.
Ctenacanthus hybodoides, Eg.
Pleuracanthus lævissimus, Ag.
Leptacanthus.
Teeth with numerous cusps (new).

Brown Mine.

Asterophyllites dubia, Brong.
Calamites approximatus, Brong.
Ulodendron majus, Lindl.
U. minus, Lindl.
Anthracomya small sp.
Anthracosia.

Megalichthys Hibberti, Ag.
Rhizodus.
Palæoniscus Egertoni, Ag.
Platysomus, 2 sp.
Ctenoptychius apicalis, Ag.
Orthacanthus cylindricus, Ag.

Close to the bottom of the lower coal measures, at Froghall and Ipstones, in the Cheadle part of the field, and separated from the millstone grit by only 1 to 14 feet of shale, there is a bed of calcareous limonite (often called red limestone) ranging from an inch to twenty inches in thickness. Its composition is as under:—

	Dried at 212° Fahr.
Peroxide of iron	52·83
Protoxide of manganese	·81
Silica	trace
Lime	14·61
Magnesia	5·70
Carbonic acid	18·74
Phosphoric acid	·32
Sulphuric acid	·28
Water	4·75
Organic matter	1·30
Total	98·74
Metallic iron	36·98

This ore also is often striped parallel to the bedding, and there are lines, like filled joints of calcite, occasionally in it. The colour of the stone varies from brown to black or red.

Derbyshire. The output from this area in 1871 was 492,973 tons; and in 1890, only 23,732 tons. The coal measures have a maximum thickness of about 3,300 feet. The ironstones occur in the middle part of them, mostly between the Waterloo Coal and the Kilburn Coal, in rocks having a thickness of about 1,400 feet.

The following section will show the relative positions of most of the workable ores:—

		Ft.	In.
UPPER COAL MEASURES.			
MIDDLE COAL MEASURES.	**Top hard** (Barnsley) **Coal**	4	6
	Strata	33	0
	Coal	0	4
	Strata	30	2
	Dunshill Coal	2	9
	Strata	37	9
	Coal	1	6
	Strata	52	3
	Blue shale with IRONSTONE	4	1
	Waterloo Coal	2	4
	Coal and clay	2	6
	Strata	18	6
	Coal	1	4
	Strata	25	8
	Coal	1	5
	Strata	52	4
	Coal	2	0
	Strata	38	6
	Coal	1	0
	Strong clay	1	0
	Soft clay with large IRONSTONE balls ...	2	7
	Strata	19	10
	TANYARD RAKE (contains 9 in. of Ironstone)	6	0
	Strata	29	1
	Coal	1	5
	Strong Coal	2	9
	Shale with IRONSTONE	3	2
	Strata	36	3
	CEMENT RAKE (in dark shale)	9	0
	Strata	65	6
	BROWN RAKE (9½ in. of Ironstone in blue and grey shale)	8	1½

Middle Coal Measures.

	Ft.	In.
Coal	0	7
Strong black clay	2	7
Coal	1	2
Strata	20	6
BLACK RAKE (10 in. of Ironstone in black shale)	5	9
Ell Coal	2	2
Strata (with three thin coals)	38	10
Deep soft Coal	3	6
Strata with some IRONSTONE	73	3
Deep hard Coal	3	11
Strong white clay with balls of IRONSTONE ...	12	2
Strata	50	10
Piper Coal	2	3
Strata with thin coal	16	2
OLD-MAN'S RAKE (4½ in. of Ironstone in white shale)	7	5½
Very strong rock	18	0
WHETSTONE RAKE (3½ in. of Ironstone in white shale)	7	3
Strata with 5 in. of coal	25	5
DOG-TOOTH RAKE (14 in. of Ironstone in dark and white shale) (Wallis' rake) ...	15	4
Strata with 8 in. of coal	43	0½
Furnace Coal	4	0
Clunch	4	5
THREE-QUARTERS RAKE (8 in. of Ironstone in light shale) (nodule rake)	9	0
Dog-tooth or Three-quarters Coal ...	1	7
Strata with 6 in. of coal	76	5
BLACK SHALE RAKE (2 ft. 3 in. of Ironstone in white shale) (striped rake)	33	6
Yard Coal	3	0
Strata with 1 ft. of coal	24	11
Black Shale or Clod Coal (Silkstone) ...	5	4

		Ft.	In.
LOWER COAL MEASURES.	Strata	40	3
	Coal	1	10
	Strata	48	11
	Coal	2	5
	Strata	52	4
	HOLLEY CLOSE RAKE in blue shale ...	21	10
	Strata	6	2
	Coal	2	3
	Strata with two thin coals	280	8
	Kilburn Coal	3	10
	Strata with three thin inferior coals	900	0
	Millstone Grit		

Below the Kilburn coal there are three rakes of ironstone, called respectively Honey Croft, Dale Moor, and Civilly rakes, that have been worked in the neighbourhood of Stanton. Several rakes have also been partially worked in the northern part of the field above the Top hard coal—viz., Brierly Bank, Inkersal, and Measure and Balls rakes.

All these ironstones occur as nodules in shale, the nodules being in rows, whence the local name "rake."

Below is a section of the black-shale rake which occurs in the country between Dronfield and Butterly.

			In.	Ft.	in.
TOP MEASURE.	WHETSTONE,	lean	1		
	Shale	... ...		1	6
	SINGLE BALLS,	do.	½		
	Shale	... ...		1	6
	DOUBLE CHITTER,	do.	2		
	Shale	... ...		3	0
	CHEESES,	good	1½		
	Shale	... ...		2	0
	BEARSTONE,	lean	1		
	Shale	... ...		2	3
	UPPER BLUES,	good	1		
	Shale	... ...		1	3

			In.	Ft.	In.
TOP MEASURE.	LOWER BLUES,	good	1½		
	Shale			2	0
	OLD-MAN,	do.	2		
	Shale			1	6
	OLD WOMAN,	do.	1		
	Shale, with irregular bed of Ironstone			12	0
LOW MEASURE.	SMOOTH CHITTER,	lean	2½		
	Shale			3	6
	FLAMPARD,	do.	3		
	Shale			2	0
	RED MEASURE,	good	1½		
	Shale			3	0
	CHANCE MEASURE,	lean	½		
	Shale			1	6
	DUN LINING,	do.	1		
	Shale			1	0
	DUN MEASURE,	do.	2		
	Shale			2	0
	OVER-LUMPS,	good	1		
	Shale			1	0
	NETHER-LUMPS	do.	1		
	Shale			1	6
	OVER-BOTTOMS,	do.	1½		
	Shale			1	6
	ROUGH MEASURE,	do.	1½		
	Shale			1	6
	BOTTOM MEASURE,	do.	1		
		2	3	33	6

The produce per acre is as follows :—

		Tons.
Cement	rake	1800
Pinder Park	„	2000
Brown	„	2500
Black	„	2000
Dogtooth	„	2000
Nodule	„	1600

			Tons.
	Black-shale	rake	4000 to 7000
	Striped	"	2500
[1]	Green close	"	1000
[1]	Holly	"	1200
[1]	Black or Kellands	"	3000
[1]	Yew tree	"	1000
	Honey croft	"	6000
	Dale moor	"	3000
	Civilly	"	4000 to 5000

The chemical constitution of the ores is shown by the following analyses, from the "Iron Ores of Great Britain," Part I.[2]

Constituents.	Swallow-wood Rake.	Brown Rake.	Black Rake.	Dog-tooth Rake.	Honey-croft Rake.	Dale Moor Rake.	Civilly Rake.
Peroxide of iron ...	·79	1·49	2·16	1·47	2·30	3·49	2·69
Protoxide of iron ...	33·72	37·99	33·56	38·97	40·01	39·55	33·31
" " manganese	1·01	1·51	·96	1·09	1·26	1·50	2·18
Silica	16·02	10·04	17·13	11·90	11·19	10·22	17·24
Alumina	6·41	5·57	8·49	5·93	5·91	5·65	8·85
Lime	3·99	4·59	3·17	1·62	2·78	3·38	2·32
Magnesia	5·49	3·37	3·06	4·82	3·05	2·88	2·71
Potash	·47	·55	·74	·67	·34	·48	·49
Carbonic acid	28·64	29·92	25·63	30·14	29·72	28·63	24·83
Phosphoric acid ...	·41	·80	·79	·48	·34	1·12	·62
Sulphuric acid ...	trace	trace	trace	trace	trace	trace	trace
Bisulphide of iron ...	·13	·06	·26	·05	·09	·05	·13
Water combined ...	·87	1·47	1·51	1·02	1·12	1·24	1·87
" hygroscopic ...	·57	·74	·74	·64	·45	·51	·70
Organic matter ...	·36	1·42	1·57	·30	1·38	1·14	1·85
Total	98·88	99·52	99·77	99·10	99·94	99·84	99·79
Metallic iron	26·79	30·60	27·15	31·34	32·73	33·20	27·79

The average metallic yield of all the ores is 30 per cent.

Anthracosia are found more or less abundantly in all the ironstones; in the Dog-tooth rake they are very plentiful.

Yorkshire (West Riding). The ironstones of this area

[1] Between black shale and Kilburn coals, at Morley Park and Alfreton.
[2] *Geological Survey Memoirs.*

occur partly in the lower and partly in the middle coal measures, the thickness of the two groups being about 2,100 feet. A section of them, as found in the northern part of the field, is given below:—

MIDDLE COAL MEASURES.

	Ft.	in.		Ft.	in.
Warren House or Gawthorpe Coal (Barnsley Coal of South part of field)	6	0	to	8	0
Measures, containing **4 thin Coals**				200	0
Top Haigh Moor Coal (Swallow-wood Coal)	2	11	to	4	6
Strata				32	0
Low Haigh Moor Coal				2	0
Strata				250	0
Joan Coal	1	9	to	2	3
Strata, containing the "COCKLE-SHELL" BED or TANKERSLEY MINE				42	0
Adwalton Stone Coal (Flockton thick)	2	8	to	4	6
Strata				36	0
Adwalton Black-bed Coal (Flockton thin)	2	6	to	3	4
Strata, containing **Brown Metal Coals**				92	0
Strata				76	0
Green Lane or Middleton Little Coal	0	6	to	3	5
Strata				70	0
Cromwell or Middleton Main Coal (= Parkgate Coal) ...	1	7	to	4	8
Strata				52	0
Three-quarters or Middleton Eleven yards Coal	1	0	to	2	0
Strata				100	0
Blocking Coal (= Barcelona and Silkstone)	1	6	to	3	2

		Ft. in.		Ft. in.
Lower Coal Measures.	Strata ...			92 0
	Lousey Coal ...			1 6
	Strata ...	53 0	to	77 0
	Coal, Churwell Thin ...	0 10	to	2 2
	Strata ...			27 0
	Coal ... (Churwell thick)			1 3
	Strata ... (Churwell thick)			25 0
	Shertcliffe-bed Coal (Churwell thick)	2 0	to	2 7
	Strata ...			190 0
	Crow Coal ...	0 4	to	2 0
	BLACK-BED IRONSTONE MEASURES ...			38 0
	Black-bed Coal ...	1 4	to	3 0
	Measures containing the "thick stone" ...			119 0
	Better-bed Coal ...	0 9	to	2 6
	Strata ...			515 0
	Halifax Hard Coal ...	2 3	to	0 4
	Strata containing **Middle-band Coals** ...			60 0
	Halifax soft Coal ...	1 6	to	0 3
	Strata ...			80 0
Millstone Grit.	Upper Grit or Rough Rock with flags at base ...			180 0

The black-bed ironstone occurs in the northern part of the field, where it has been largely worked at Low Moor and Bowling. In the southern part of the field, between the Barnsley and Silkstone coals, several ironstone measures have been worked. The Claywood or black shale mine, 18 to 42 feet above the Silkstone coal, and the Tankersley or mussel-band, 10 to 20 feet above the Flockton thick coal, are the most important. The latter extends also into the northern area. There are also in the south, the Swallow-wood, over and near the

coal of that name, that is about 60 yards below the Barnsley coal; the Lidgate, about 50 yards above the Tankersley; the Thorncliffe black mine, about 75 feet above the Parkgate coal; and the Thorncliffe white mine, immediately below the Parkgate coal.

Sections of the measures vary greatly in different areas. Those following are given simply to illustrate the mode of occurrence of the ironstone:—

Black-bed Ironstone (workable part).

	In.	In.
IRONSTONE	2	
Black shale		10
IRONSTONE	2	
Black shale		10
IRONSTONE	2	
Black shale		8
IRONSTONE	3½	
Black shale		6
IRONSTONE	1	
Black shale		5
Black-bed Coal		

The thickness of workable ironstone in these measures varies throughout the district from 3 ft. to 10½ in., and the associated shale from 1 ft. 10 in. to 6 ft. 8 in. In the measures (5 feet thick) immediately above this section there are several courses of ironstone known as the "white-bed." The quality of the ore, however, is not so good as that of the "black-bed."

Claywood Ironstone.

	Ft.	In.	Ft.	in.
IRONSTONE (in two beds)		4		
Grey shale			6	0
IRONSTONE (bed)		4		
Dark shale			3	0
IRONSTONE (bed)				
Black shale with nodules of Ironstone ...		4		6½
Total	1	0	9	6½

The thickness of these measures varies in different districts from 5½ feet to 17 feet.

Tankersley Ironstone (in the south).

	In.	Ft.	in.
Shale (light-coloured)			
IRONSTONE	2½		
Black shale with nodules of Ironstone ...		3	0
IRONSTONE	3		
Strata		19	6
Flockton Thick Coal			

Tankersley Ironstone (in the north).

	In.	Ft.	in.
IRONSTONE	2		
Black shale			9
IRONSTONE	3		
Black shale		1	0
IRONSTONE	3		
Black shale			7
Adwalton Stone Coal			

The measures range in thickness from 2 to 13 feet, the ore from 5 to 8 inches.

The produce per acre from these measures is as under :—

	Tons.		Tons.
Tankersley	2000	to	3000
Thorncliffe black mine	1500		—
" white "	1500		—
Claywood	1500	to	1600
Black-bed	1200		—

The ironstones occur partly as thin beds, and partly as nodules. Some of the nodules contain thin veins of barite and calcite; others films of pyrite. *Anthracosia* are met with in some of them, especially the Tankersley.

The composition of the ores has been determined by analysis,[1] as set forth in the subjoined table :—

[1] *Geological Survey Memoirs,* "Iron Ores of Great Britain," Part I.

Constituents.	Black-bed Mine (Low-Moor).	Black Mine (Thorn-cliffe).	White Mine (Thorn-cliffe).	Clay Wood (Park-gate).
Peroxide of iron	1·45	2·39	1·69	1·30
Protoxide of iron	36·14	41·77	39·38	39·87
" " manganese ...	1·38	1·13	·95	1·38
Silica	17·37	8·93	12·16	13·50
Alumina	6·74	4·79	6·42	6·13
Lime	2·70	2·55	2·26	2·12
Magnesia	2·17	3·85	3·89	2·77
Potash	·65	·43	·37	·18
Carbonic acid	26·57	31·39	29·38	28·47
Phosphoric acid	·34	·75	·47	·69
Sulphuric acid	trace	trace	—	trace
Bisulphide of iron	·10	trace	trace	·05
Water combined	1·16	1·15	1·41	1·21
" Hygroscopic	·61	·55	·68	·59
Organic matter	2·40	·86	·54	·83
Total	99·78	100·54	99·60	99·09
Metallic iron	29·12	34·16	31·82	31·92

The average metallic yield of these ores is about 32 per cent.

Northumberland and Durham. Ironstone has been worked in both the lower and middle coal measures here, but only in a small way, and has now ceased altogether. A seam about 4½ inches thick was worked about 18 inches above the high main, another 2 inches thick formed the roof of the Hutton-seam; and low down in the measures, at Shotley Bridge, ironstone was also obtained.

Again, ironstone has been worked at Redesdale and Hareshaw, in the carboniferous limestone series, which, there, is so much split up by sandstones, shales, and coal, that we seldom find a bed of limestone exceeding 20 feet in thickness. The ironstone has been chiefly worked on one horizon (lower Bernician), where it occurs as nodules (spherical or flattened) in a bed of shale about 30 feet thick. This bed was worked opencast some years ago for a considerable distance. It was said to yield over 5,000 tons per acre. The nodules contain strings of calcite—apparently filled cracks.

Scotland. North Staffordshire and Scotland are, at the present time, the principal sources of argillaceous ironstone in

the country. Together they produce about six-sevenths of that description of ore now being raised.

As already stated, the ironstones of Scotland are raised partly from the coal measures, and partly from the middle and lower part of the carboniferous limestone series. The latter are locally known as the lower coal measures, from the occurrence in them of several beds of valuable coal.

Some ironstones are also found in the millstone grit, or moor rock.

The following section at Muirkirk, in the Ayrshire coalfield, will serve to illustrate the position of these ironstones :—

		Ft.	in.
COAL MEASURES.	**Coal**	2	6
	Strata	12	0
	Coal	5	0
	Strata	66	0
	THREE-FOOT COAL (Claud)	3	3
	Strata	54	0
	SEVEN-FOOT COAL (Maid)	7	0
	Strata	3	0
	Coal (Low Maid)	3	0
	Strata	108	0
	Coal	2	4
	Strata	126	0
	MUSSEL-BAND IRONSTONE (Kiltongue)	0	6
	Strata	18	0
	Five-foot Coal	5	6
	Strata	18	0
	Six-foot Coal	6	6
	Strata	138	0
	BLACKBAND IRONSTONE (upper slaty) ...	1	0
	Strata	60	0
	THIN BLACKBAND (lower slaty)	0	6
MILLSTONE GRIT (Moor Rock).	Strata consisting chiefly of sandstones, grits, fireclays, and thin coals	840	0

			Ft.	in.
Carboniferous Limestone Series.	Upper.	Bluetour limestone	52	0
		Bluetour Coal	8	0
		Strata	60	0
		Limestone	2	0
		Strata	90	0
		Tibby Pagan's limestone	6	2
		Strata	72	0
		Coke-yard Coal	3	6
		Strata	78	0
		Limestone	4	0
		Strata	48	0
		Limestone	1	3
		Strata	30	0
		Ell-Coal Limestone	2	3
	Middle.	Strata	36	0
		Ell Coal	4	0
		Strata	4	0
		BLACKBAND AND IRONSTONE	0	10
		Strata	36	0
		Seven-foot Coal	11	2
		Strata	30	0
		Nine-foot Coal	7	6
		Strata	30	0
		HIGH-BAND IRONSTONE (clay)	1	2
		Strata	30	0
		MID-BAND IRONSTONE (clay)	1	3
		Strata	6	0
		Thirty-inch Coal	2	6
		Strata	30	0
		Six-foot or Catchybun Coal	6	0
		Strata	48	0
		LOW-BAND IRONSTONE (clay)	1	0
		Strata	12	0
		McDonald Coal	5	0
		Strata	12	0
		McDONALD IRONSTONE (clay)	1	2
		Strata	2	0

			Ft.	in.
CARBONIFEROUS LIMESTONE SERIES.	Lower.	McDonald Limestone	36	0
		Strata	30	0
		SMITH IRONSTONE (clay)...	0	4
		Strata	12	0
		Limestone	3	0
		Strata	2	3
		CROSSFLATT IRONSTONE (clay) ...	0	6
		Strata	18	0
		Hawthorn limestone	21	6
		Wee limestone		
		Calciferous sandstone series		

The carboniferous limestone series, over a very large area, is divisible into three groups, as shown above; the upper and lower containing coals and thin limestones, interstratified with sandstones and shales; the middle containing coals but no limestone. The chief repository of ironstone is the middle and lower groups. Taking first the ironstones occurring in the limestone series, those found at Muirkirk and Lugar are shown in the above section. In the Dalry district there are two principal ironstones worked, both of which occur in the middle group; one, a blackband, occurring about 30 fathoms below the Borestone coal, and varying in thickness from 4 to 14 inches, the other, a clayband, about 32 fathoms lower, and ranging from 12 to 18 inches in thickness.

In the southern part of the Ayrshire coalfield a seam known as the Burnfoot blackband is worked. It varies in thickness from 2 inches at Cumnock to 27 inches at Dalmellington; and is considered to be the equivalent of the slaty band, at the base of the coal measures, in the Clyde basin.

In the Clyde basin the coal measures contain the ironstones named in the subjoined table:—

	Ft.	in.
PALACE-CRAIG IRONSTONE (Blackband) ...		9
Strata	96	0
Upper Coal	5	0
Strata	104	0

	Ft.	in.
Ell Coal	5	6
Strata	38	0
Pyotshaw Coal	4	0
Strata	21	0
Main Coal	4	2
Strata	54	0
Humph Coal	2	5
Strata	36	0
Splint Coal	4	3
Strata	9	0
Virgin Wee or Sourmilk Coal	2	3
Strata	72	0
AIRDRIE OR QUARTER BLACKBAND IRONSTONE varies from 1 ft. to 1 ft. 6 in. ...	1	4
Strata	96	0
NEWARTH-HILL AND CLELAND ROUGH-BAND IRONSTONE B.B. 2 in. to 8 in. ...		6
Strata	9	0
Virtuewell Coal	2	4
Strata	27	0
BELLSIDE IRONSTONE, B.B. from 5 in. to 9 in.		6
Strata	72	0
KILTONGUE MUSSEL-BAND IRONSTONE, B.B. from 1 ft. 4 in. to 1 ft. 8 in.	1	3
Strata	33	0
Kiltongue Coal	3	6
Strata	33	0
Upper Drumgray Coal (furnace)	2	0
Strata	39	0
Lower Drumgray Coal (smithy)	2	3
Strata	240	0
[1] UPPER SLATY IRONSTONE, B.B. 0 ft. to 3 ft. 6 in.	1	2
Strata	99	0
LOWER SLATY IRONSTONE, B.B. 0 in. to 8 ft. 0 in.	1	10

[1] Position of Burnfoot Blackband in Ayrshire.

In the same area the ironstones of the carboniferous limestone series occur in the middle group, and are less constant in horizon than the ironstones of the coal measures passing under a variety of names in different parts of the field. They occur both as blackbands and claybands.

Speaking generally, the ironstones occur as beds or seams of variable thickness, and frequently assume a lenticular form. Some of the blackbands have been traced into coal, as, for example, that worked at Craigmark, Dalmellington; which passed eastward into a gas coal. The lower slaty ironstone of the Clyde basin is also occasionally replaced by coal. The claybands frequently become poorer--more limy—as the thickness increases.

The chemical composition of the ores is indicated by the following analyses :—

Constituents.	Blackbands.				Claybands.			
	1	2	3	4	5	6	7	8
Peroxide of iron ...	·23	—	—	—	—	—	—	—
Protoxide " " ...	53·03	32·14	41·65	34·71	37·54	24·90	47·31	38·31
" " manganese	—	1·05	—	—	3·60	1·22	trace	—
Silica	1·40	12·40	·52	4·56	11·20	6·80	10·12	6·32
Alumina	·63	7·06	·96	2·85	6·23	3·27	7·10	5·82
Lime	3·33	2·82	5·76	5·02	6·50	16·55	·97	8·75
Magnesia	1·77	1·08	3·52	1·20	·43	7·54	·91	3·41
Carbonic acid ...	35·17	22·87	33·08	26·47	28·94	35·61	30·22	34·04
Phosphoric acid ...	—	·82	·84	·36	1·92	1·76	·49	1·02
Sulphur	—	·22	·25	·36	·27	·31	trace	·23
Iron combined with sulphur ...	—	·19	·22	·32	·24	·27	—	·20
Bituminous matter	3·03	18·60	11·16	22·71	2·03	·73	2·32	1·02
Water	1·41	·75	2·04	1·44	1·10	·52	·56	·88
Total	100·00	100·00	100·00	100·00	100·00	99·48	100·00	100·00
Metallic Iron ...	39·40	25·19	32·62	27·32	29·41	19·63	36·80	30·00
Specific gravity ...	—	—	—	2·38	—	—	—	3·32

No. 1 is Mushet's or the Airdrie blackband, No. 4 Dalry blackband, and No. 8 Dalry clayband. The average metallic yield of the blackbands may be taken at 34 %, of the claybands 30%. Specific gravity of the blackband ironstones 2·1 to 3·69, of the clay-bands 2·81 to 3·5.

Both the blackbands and claybands fluctuate considerably in thickness, and also in quality. In the former the iron varies from 25 to 40%, in the latter from 19 to 37%. The earthy materials in the ores vary from 5½ to 24% in the blackbands, and from 19 to 25% in the claybands. Some of the latter contain as much as 17% of lime. They effervesce freely when treated with acid—in some parts more than others. Take the case of the Dalry clayband; it is more limy in the lower part than in the upper.

The blackband ironstones also contain lime in places. In them, however, it occurs in lenticular bands, and is not distributed through the mass as in the claybands. The bituminous matter of the blackbands occurs throughout the stone in irregular layers, sometimes not thicker than a sheet of paper, at other times as much as half an inch or more in thickness. The alternating coal and irony matter frequently give the stone quite a striped appearance, and occasionally, as in the slaty band, this is accompanied by a fissile structure.

A list of the organic remains yielded by these ores will be found in the following table (partly after the Geological Survey):—

In the Carboniferous Limestone Series.

Dalry Blackband Ironstone.

Cyclopteris orbicularis (?), Brong.
Lepidodendron gracile, Lindl.
Anthracomya modiolaris, Sow.
Nautilus subsulcatus, Phill.
Myalina modiolaris, Sow.
Leptacanthus junceus, M'Coy.
Megalichthys Hibberti, Agass.

Dalry Clayband Ironstone.

Leperditia Scoto Burdigalensis, Hibb.
Lingula squamiformis, Phill.
Rhizodus Hibberti, Agass.

Lingula Ironstone (Carluke).

Avicula prisca, M'Coy.
Aviculopecten duplicicosta, M'Coy.
„ fallax, M'Coy.
Pinna Ivaniskiana, M. V. & K.
Arca arguta, Dekon.
Cardiomorpha tenera, Dekon.
Cypricardia oblonga, M'Coy.
Edmondia prisca, M'Coy.
Leptodomus fragilis, M'Coy.
Lithodomus Jenkinsoni, M'Coy.
Modiolo lingualis, Phill.
„ Macadami, Porth.
Naticopsis elliptica, Phill.
„ Omaliana, Dekon.

Blackband Ironstone underlying *Lesmahagow Gas Coal* (base of Middle Limestone Series).

Stigmaria.
Spirorbis carbonarius, Murch.
Entomostraca.
Anthracomya, Sp.
Myalina, Sp.
Lingula Squamiformis, Phill.
Acanthodes Wardi, Eg.
„ sulcatus, Ag.
Cælacanthus, Sp.
Ctenoptychius, Sp.
Gyrolepis (one ramus of small jaw).
Megalichthys Hibberti, Ag.
Palæoniscus, Sp.
Rhizodus Portlockii, Ag.
Coprolites (plentiful).

McDonald Clayband, Ironstone, and Shales.

Athyris, Sp.
Discina nitida, Phill.
Lingula squamiformis, Phill.
Productus longispinus, Sow.
 „ punctatus, Mart.
 „ semireticulatus.
Rhynchonella, Sp.
Spirifera Urei, Flemg.
Aviculopecten, Sp.
Pecten Sowerbii, M'Coy.
Leda attenuata, Flemg.
Leptodomus costellatus, M'Coy.
Myalina, Sp.
Schizodus deltoideus, Phill.
Solenopsis minor, M'Coy.
Euomphalus carbonarius, Sow.
Macrocheilus, Sp.
Bellerophon, Sp.
Orthocerus affine, Sow.
 „ (large, Sp.).
Petalodus Hastingsæ, Owen.

IN THE COAL MEASURES.

Slaty Band.

Lepidostrobus, Sp.
Lingula mytiloides, Sow.
Asterophyllites charæformis, Sternb.
Ulodendron Lindleyanum.

Kiltongue Mussel-band.

Calamites.
Lepidodendron Sternbergii, Brong.
Anthracosia acuta, Sow.
 „ Sp.

Airdrie Blackband.

Lepidostrobus levidensis.
„ tennis.
„ Russellianus.
Beyrichia arcuata.
Anthrapalæmon Grossarti, Salter.
Spirorbis carbonarius, Murch.
Lingula squamiformis, Phill.
Anthracosia phascola, Sow.
„ centralis, Sow.
„ ovalis, Mart.[1]
Rhizodopsis (scales).
Strepsodus (teeth).
Megalichthys coccolepis, Young.
„ rugosus, Young.
Uronemus magnus, Trag.
Anthracosaurus Russelli, Hux.
Megalerpeton plicideus, Young.
„ simplex, Young.
Pteroplax cornuta, H. & A.
„ brevicornis, Young.
Pholoderpeton, Sp., Hux.[2]
Cladodus lœvis, M'Coy.
Harpacodus dentatus, Ag.
Gyracanthus tuberculatus, Ag.

Palace-craig Blackband.

Calamites, 2 Sp.
Lepidodendron, Sp.
Lepidostrobus, Sp.
Estheria tenella.
Leperditia Scoto-burdigalensis, Hib. (?).
Prestwichia, Sp.
Anthracoptera, Sp.

[1] Also in Bellside ironstone.
[2] Also in Palace-craig blackband.

Ctenodus (scales).
Megalichthys Hibertii Agass, jan, etc.
" scales, etc.
Pleuracanthus gibbosus, Agass.
Ctenacanthus major, Agass.
Ctenoptychius pectinatus, Agass.
Diplodus gibbosus, Agass.
Pleurodus affinis, Agass.
Calacanthus leptarius, Agass.
Dendroptychius Sp., Hux.

General Observations on Argillaceous Ironstones.

One of the first things that strikes us in a study of these ores is the existence of crack-like cavities in the nodules, and their absence from the beds, or seams, of ironstone. Both forms of ore are intersected by the two sets of vertical jointing usual in rocks, and also by more or less evident bed-jointing; but in the larger nodules these joints, or some of them, seem to be widened toward the centre, so that cavities are formed which, in section, have frequently a lenticular shape. The outer part of the nodules are more or less concretionary, and the crack-like cavities mentioned do not extend into this part of the ore. Nor do they appear in the smaller nodules; but when a certain size is reached the cavities are found as slightly widened vertical joints. These, as the nodules increase in size, become longer and wider. Other cavities then appear along the bed-joints, and in the largest nodules a most complicated network of cavities is found, many of which are filled, wholly or partially, with other substances. These cavities are usually supposed to be cracks, due to contraction; but, as will be shown later, they have presumably a very different origin.

Vegetable and animal remains are found alike in nodules and in seams or beds, frequently lying side by side, and many of them converted into carbonate of iron. In the beds they are quite flattened.

In those ironstones resting on coal seams it is not uncom-

mon to find short thin layers of *pure* coal, enclosed in the ironstone, which have no connection whatever with the underlying seam.

The specific gravity of blackbands, speaking generally, is less—sometimes very much less—than that of claybands, a fact doubtless due to the large admixture of carbonaceous matter in the former; though, at the same time, they contain less argillaceous matter than the claybands. For the same reason the loss in calcination is greater in blackbands than in claybands; but the metallic yield is then proportionately greater in the former than in the latter.

The following table, giving the average percentage weights of the iron and the more important rock-forming minerals in the clay ironstones of different parts of the country, is interesting from several points of view. In the first place it shows that whatever variations there may be in the relative amounts of iron and silica, the ratio of silica to alumina is fairly constant, and is about 2 to 1. It further shows that lime is the most variable, in quantity, of any mineral in these ores, and that when the iron is low the lime and magnesia are high.

	Metallicerin.	Silica.	Alumina.	Lime.	Magnesia.
South Wales	31·40	11·59	5·51	4·29	3·71
Shropshire	37·18	7·71	3·74	2·57	2·10
Staffordshire (South)	34·75	10·64	4·67	2·37	1·85
„ (North)	37·16	5·59	2·65	2·57	1·89
Derbyshire	29·94	13·39	6·60	3·00	3·62
Yorkshire	31·75	12·99	6·32	2·41	3·17
Scotland	30·00	8·61	5·60	8·19	3·07
Average	33·17	10·08	4·98	3·61	2·77

CHAPTER VII.

THE IRON ORES OF THE SECONDARY ROCKS.

I. Introductory.

THIRTY years ago the bulk of the ore used in British iron manufacture was obtained from the carboniferous rocks, and only about 10 per cent. came from the secondaries. Now, about 56 per cent. of the raise comes from these rocks, as will be seen from the following table :—

Ores raised and consumed in the United Kingdom.

	In 1855.		In 1890.
From the Secondary rocks ...	1,044,384	...	9,060,169
" " Carboniferous rocks ...	8,478,860	...	4,838,977
" " other rocks	30,497	...	54,792
Total	9,553,741	...	13,953,938

The fall that has taken place in the quantity of ore coming from the carboniferous rocks is confined almost entirely to the earthy carbonates of the coal-measures, as there has been a very considerable increase in the oxides yielded by the carboniferous limestone. This will be rendered clear by the table that follows :—

Ores raised from the Carboniferous Rocks of the United Kingdom.

	In 1855.		In 1890.
Carbonates, mainly from the Coal-measures	7,848,635	...	2,414,017
Oxides from the carboniferous limestone	630,225	...	2,424,960
Total	8,478,860	...	4,838,977

It is thus seen that the output from the coal-measures has, during the time embraced in these tables, fallen about 46 per cent., whilst that from the secondary rocks has increased nearly 900 per cent.

Notwithstanding this enormously increased importance of the ores from the secondary rocks, comparatively little is known regarding them, with the exception of those of Cleveland and Northamptonshire. A list of the more important works containing references to the subject will be found below :—

1857. "Outline of the Main or Stratified Ironstone at Cleveland," by John Marley. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. v.

1857-8. "Ironstone of Rosedale Abbey," by Joseph Bewick. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. vi.

1858. "On some Comparative Sections in the Oolitic and Ironstone Series of Yorkshire," by John Phillips. *Quarterly Journal of the Geological Society*, vol. xiv.

1858-9. "Magnetic Ironstone in Rosedale," by Nicholas Wood. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. vii.

1859. "Geology of the Country around Woodstock," by E. Hull. *Memoir of Geological Survey*.

1861. "Geological Treatise of the District of Cleveland, in North Yorkshire," by Joseph Bewick.

1869-70. "Magnetic Ironstone of Rosedale Abbey," by John Marley. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. xix.

1870. "The Oolites of Northamptonshire," Part 1, by Samuel Sharpe. *Quarterly Journal of the Geological Society*, vol. xxvi., part 3.

1870. "Additional Observations on the Neocomian Strata

of Yorkshire and Lincolnshire," by J. W. Judd. *Quarterly Journal of the Geological Society*, vol. xxvi., part 3.

1872. "Geology of the Neighbourhood of Banbury," by Thomas Beesley.

1873. "The Oolites of Northamptonshire," Part 2, by Samuel Sharpe. *Quarterly Journal of the Geological Society*, vol. xxix., part 2.

1875. "Geology of North-West Lincolnshire," by Rev. J. E. Cross. *Quarterly Journal of the Geological Society*, vol. xxxi., part 2.

1875. "Geology of Rutland," by J. W. Judd. *Memoir of Geological Survey.*

1875. "The Beds of Ironstone occurring in Lincolnshire," by J. Daglish and R. Howse. *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. 24.

1876. "The Yorkshire Oolite," Part 2, by W. H. Hudleston. *Proceedings of the Geological Association.*

1876. "The Frodingham Ironfield," by George Dove, Jun. *Journal of the Iron and Steel Institute.*

1877. "On the Corallian Rocks of England," by J. F. Blake and W. H. Hudleston. *Quarterly Journal of the Geological Society*, vol. xxxiii., part 2.

1877. "The Yorkshire Lias," by Tate and Blake.

1880. "The Resources of the Cleveland Ironstone," by G. Barrow. *Proceedings of the Cleveland Institute of Engineers.*

1881-2. "The Iron Ores and Mines of Cleveland," by Thomas Allison. *Proceedings of the Cleveland Institute of Engineers.*

1885. "The Iron Industry of Frodingham," by G. Dove. *Proceedings of the Institute of Mechanical Engineers.*

1886. "The Iron Ores of the English Secondary Rocks," by J. D. Kendall. *Transactions of the North of England Institute of Mining and Mechanical Engineers.*

Partial Description of the Secondary Rocks.

The ores now to be described occur in the Jurassic and Cretaceous rocks, which are usually subdivided as below.

Cretaceous ...	Upper ...	... Chalk.
		Upper greensand.
		Gault.
	Lower ...	... Neocomian.
Jurassic	Upper Oolite	... Purbeck beds.
		Portland „
		Kimmeridge clay.
	Middle „	... Coralline rocks.
		Oxford clay.
	Lower „	... Cornbrash.
		Forest marble.
		Great oolite.
		Fuller's earth.
		Inferior oolite.
	Liassic ...	... Upper lias.
		Middle „
		Lower „

It is only intended to notice those ores that either are or have in recent times been worked somewhat extensively. These all occur below the Gault, and are confined to a few horizons, as will be seen on reference to Plate II. The rocks in which they are found rise to the surface in two main areas. One forms an irregular band, extending from the sea coast on the north of Yorkshire to that on the south of Dorsetshire (a distance of about three hundred miles), having a maximum breadth of about fifty-eight miles, and a minimum breadth of less than a quarter of a mile. The other area, which is much smaller, occurs in the counties of Hampshire, Surrey, Sussex, and Kent. Although famous as an iron-making district upwards of two hundred years ago, this latter area does not now, and has not, for more than sixty years, produced any iron ore, for the simple reason that it is too far from the coalfields. In its days of prosperity there was plenty of timber from which charcoal could be made. Both the areas referred to are shown on Plate III., Fig. 1, the larger being hatched at different angles in

its several parts (lettered respectively *a*, *b*, *c*), to indicate the areas occupied by the Liassic, Oolitic, and Neocomian rocks respectively. The smaller area (lettered *c*) contains only rocks of Neocomian age. Plate III., Fig. 2, gives a generalised section of the strata in the larger area. Generally speaking, the dip of the beds in that area is to the south-east, as shown on the section. The angle of dip is usually low, the beds being at times nearly level. This south-easterly dip is, in a great measure, due to the thinning of the beds in that direction, as shown in Figs. 3 and 4, which are taken along approximately north-west and south-east lines.

The different members of the Jurassic system are fairly comformable to one another, and so are those of Cretaceous age, which have to be dealt with; but there is a great unconformity between the two rock systems. This will be best understood by reference to Plate III., which shows how the Cretaceous rocks overlap those of the system below. South of the Wash there is a broad band of Oolitic rocks, between the Lias and Neocomians, but as the Humber is approached this band becomes gradually narrower, and at about twelve miles north of that river it disappears altogether, and the cretaceous rocks rest directly upon the Lias. The unconformity is equally marked in other areas, but the grouping together of the oolitic rocks in Plate III. does not permit it to be shown.

On reference to Plate II. it will be seen that there is a considerable difference in the thickness of the various members of both the Liassic and Oolitic rocks, as they occur between Yorkshire and Wiltshire. This arises mainly from the south-easterly attenuation of the strata already pointed out. There are also important changes in the lithological characters of some of the rocks, as will appear from the following summary of those characters exhibited by the formations in different parts of their course.

Lower Lias may be said to consist generally of blue shaly clay, with a few thin beds of limestone in its lower part, especially near the base.

Middle Lias, or marlstone, is divisible into two parts,

the upper, or "rock bed," consisting of argillaceous limestone generally, but sometimes partly or wholly of argillaceous or calcareous ironstone. The lower member includes sands (sometimes sandstones), and clay or shale.

Upper Lias. This formation consists generally of bluish shaly clay, with nodules of earthy limestone, but at places, as in Cleveland, it includes grey shivery shales.

Inferior Oolite. This is perhaps the most variable formation of any that has to be dealt with, and has given most trouble to geologists. In Wiltshire it consists entirely of calcareous rocks. In Mid-Oxfordshire it is also calcareous; but the thickness is greatly reduced, and it appears to be the equivalent of only the uppermost part of the formation as developed in Wiltshire, the lower portion having thinned off in the manner already alluded to before reaching this part of Oxfordshire. In Northamptonshire the formation consists largely of sands and sandstones, the upper part, in places, containing irregular calcareous beds. The lower part frequently occurs as an iron ore. In Mid-Lincolnshire it presents two separate divisions over a considerable area, the lower part being iron ore, the upper limestone (the Lincolnshire limestone). In North Yorkshire the formation is made up of alternations of sandstone and shale, known as the Estuarine series, in which a bed of limestone, called the Millepore bed, occurs about three-quarters up from the base.

The rocks between the inferior oolite and the Coral rag do not contain iron ore in workable quantities, so far as is known, so that it will be unnecessary to notice them.

The rocks associated with the ore of the Coral rag, and the Neocomians, will be described later on.

II. Detailed Description of the Ores.

Deposits in the Lower Lias.

The only deposit of ore in these rocks, that has been worked up to the present time, occurs at Frodingham in North Lincolnshire. Its vertical position is shown on Plate II. For a long

time it was considered, and perhaps by some is still thought, to be the equivalent of the Cleveland main bed, but there is now not any doubt whatever that it is in a much lower geological horizon. It occurs in the zone of *A. semicostatus*, which in Cleveland is about 480 feet below the main seam of ore, although at Frodingham it is only about 161 feet below the equivalent of the latter bed, owing to the south-easterly attenuation of the rocks, as previously mentioned. The ore occurs in the form of a bed, with a gentle inclination towards the east. Its maximum thickness is only about 25 feet, but owing to its slight dip, combined with the level nature of the ground, its outcrop occupies a wide stretch of country.

The geological horizon in which the ore occurs will be seen from the following section, obtained in sinking a shaft to the ore between Appleby village and the railway station :—

		Ft.	In.	
	Limestone (Lincolnshire) ...	36	8	
Upper Lias	Blue shale	34	4	
	Sandstone	1	11	
	Grey shale	25	10	A. Communis.
Middle Lias	**Ironstone** (Cleveland main seam)	7	10	" Spinatus.
Lower Lias (upper part of)	Shale with cement-stone nodules	67	6	" Capricornus.
	Ironstone (Pecten bed) ...	4	6	" Armatus.
	Blue shale	89	9	" Raricostatus.
	Ironstone (Frodingham main bed)	22	6	" Semicostatus.

Below the main bed of ore to the bottom of the Lias there are probably about 200 feet of bluish clay with thin limestones. The ammonites, mentioned on the right of the section, were not found in the sinking, but in corresponding beds not far from it.

The working of the ore bed is, at present, confined to its outcrop, and to the dip side thereof. The "rise" part of the bed under the village of Frodingham, and to the west, is not considered worth working. Where the ore is worked it is merely covered by fine yellow sand, varying from 1 to 20 feet in thickness.

As already mentioned, the working is confined to the dip side of the outcrop. The bottom part of the bed being very low in iron, and the workable portions above it containing three limestone bands in its lower half, it will be readily understood why the deposit under Frodingham, and to the west, is so much inferior to the eastern part of the outcrop. The greatest thickness of the workable part of the ore bed may perhaps be taken at 16 feet, and the average at about 12 feet. When looked at from a little distance, the ore has a distinctly bedded appearance, which is decidedly increased by the occurrence of the calcareous bands, as they are of a much lighter colour than the more orey parts of the bed. But apart from these lighter coloured bands the ore itself is distinctly bedded, the beds being thin and irregular, as shown in the section below :—

	Ft.	In.
Fine yellow sand (surface covering)	1	6
Iron Ore, very open-jointed and much disturbed ...	2	0
„ „ more compact	0	8
Ferruginous limestone	2	0
Iron Ore	3	4
Ferruginous limestone	1	0
Iron Ore	0	11½
Ferruginous limestone	0	9
Iron Ore	0	7
Ferruginous limestone	1	7½
Iron Ore	0	7
Total thickness of ore and limestone	13	6

The general colour of the ore is snuffy-brown.

The laminæ of the top layer of ore are much thinner than any of those below, and they are much more broken up. They seem to have been subjected to some disturbance, as the small thin pieces in which the ore now exists form anticlinals and synclinals almost throughout the layer. This part of the bed is also much less compact than those below.

Sometimes, in the midst of the brown ore, a nodule, or a discontinuous layer of nodules, of greenish or greyish ore may be seen, especially in the lower part of the bed; in fact, they

seem to be entirely absent from the upper part. They have usually a flattened form, and the brown ore immediately adjoining them is darker and much more compact than the rest. The ore reached by the sinking between Appleby and the station was entirely green and grey. Both the brown and the green ore have a prevailing pelitic appearance, though both are oolitic in places. This latter structure occurs in a very interrupted manner, but still it is so frequent, that a piece of the size of a man's hand is almost sure to exhibit it to some extent. Many of the oolitic grains are hollow.

The limy bands, which graduate on both sides into the ore, contain numerous fossils, and so does the ore, the same species being found in both. The prevailing forms belong to the genera *Cardinia* and *Gryphæa*. So abundant is *Gryphæa incurva*, that one or more specimens may be found in almost every piece of any size that is lifted. The Rev. J. E. Cross,[1] who has devoted considerable time to the geology of the district, has obtained from the ore bed a great variety of organic remains, as shown by the following list:—

Ammonites Bucklandi (?), Sow.
„ Conybeari, Sow.
„ semicostatus, Y. and B.
„ Brookii, Quenst.
„ aureus, Dumortier.
„ Gmundensis, Dumortier.
„ Boucaultianus, D'Orb.
„ scipionanus (?), Quenst.
„ compressarius (?), Quenst.
Nautilus striatus, Sow.
Belmnites acutus, Mill.
Pleurotomaria anglica, Sow.
Tancredia ferrea, n. sp.
Cardinea gigantea, Quenst.
„ Copides (?), Rickh.

[1] "Geology of North-West Lincolnshire," *Quarterly Journal of the Geological Society*, vol. xxxi., 1875.

Cardinea crassissima (?).
 „ Morrisii (?), Terq.
 „ n. sp.
Astarte dentilabrum, Ether.
Cucullea ovum, Quenst.
Pholadomya ambigua, Sow.
Myoconcha oxynoti, Quenst.
Modiola oxynoti, Quenst.
 „ Morrisii, Oppel.
Hippopodium ferri, n. sp.
Gervillia betacalcis, Quenst.
Lima gigantea, Sow.
 „ „ small var.
 „ Hermanni, Voltz.
 „ hèttangiensis, Terq.
 „ dupla, Quenst.
Pecten equalis, Quenst.
 „ duressus, large smooth.
 „ texturatus, Goldf.
Gryphæa incurva, Sow.
Carpentaria, sp. (Terquemia).
Spiriferina Walcotti, Sow.

Most of the shells retain their limy character, but in some the lime has been partly, in others wholly, replaced, by carbonate or hydrated peroxide of iron.

The quality of the bed is very unequal in its different layers. The variations will perhaps be best illustrated by the method adopted in the table on next page. The analyses therein given were made soon after the samples had been taken from the bed, so that the percentage of hygroscopic water in them is very nearly the proportion which actually exists in the different parts of the bed *in situ*.

It will be seen from these analyses that the bulk of the ore is a hydrated peroxide or limonite, not very rich in iron, and that it is best at the top. In the course of working, a considerable portion of the limy beds is rejected; but even then,

PERCENTAGE WEIGHTS.

	Thickness of Layer.		Metallic Iron.	Carbonate of Lime.	Water at 212° Fahr.	Combined Water.	Peroxide of Iron.	Protoxide of Iron.	Insoluble Silicious Matter.	Alumina.	Manganese Binoxide.	Lime.	Magnesia.	Phosphoric Acid.	Sulphuric Acid.	Bisulphide of Iron.	Carbonic Acid.
	Ft.	In.															
A	2	0	34·20	5·25	16·10	7·84	48·85	—	13·57	4·22	1·93	2·94	0·58	1·01	trace	—	2·96
B	0	8	28·34	21·55	10·12	7·53	40·49	—	10·92	4·11	2·26	12·07	1·02	·85	·02	—	10·61
C	2	0	23·66	32·75	13·19	4·89	33·80	—	7·17	4·32	1·53	18·34	·73	·76	·05	—	15·22
D	3	4	28·38	24·87	14·00	6·64	40·55	—	5·55	4·36	1·63	13·93	·73	·86	·02	—	11·74
E	1	0	26·17	35·41	3·21	1·96	16·52	18·61	2·34	1·35	1·91	19·83	2·30	1·05	—	·25	30·68
F	0	11½	31·36	16·55	16·58	7·37	44·80	—	6·12	4·27	1·89	9·27	·75	·81	·02	—	8·12
G	0	9	18·40	51·73	7·82	3·90	26·29	—	3·07	3·00	·85	28·97	·81	1·19	trace	·43	23·67
H	0	7	25·47	20·94	13·25	4·58	32·35	2·26	12·18	5·43	1·97	11·73	1·18	·90	trace	2·27	11·90
I	0	3	18·67	49·28	8·10	3·48	20·87	5·01	5·04	3·11	·84	27·59	1·12	·52	trace	·35	23·97
J	0	4	13·91	62·50	5·34	1·84	19·83	—	4·06	2·65	·84	35·00	1·02	·69	trace	·07	28·66
K	0	4½	11·54	68·28	3·74	1·64	12·17	3·26	3·54	2·40	1·32	38·23	·91	·99	trace	1·03	30·77
L	0	4½	16·80	55·88	6·99	2·72	20·08	3·49	5·54	2·72	1·19	31·29	1·06	·51	trace	·07	24·34
M	0	3½	10·69	71·38	2·21	1·23	8·51	4·14	3·00	1·80	1·71	39·97	1·10	·75	trace	3·24	32·34
N	0	7	28·00	23·40	8·63	3·48	24·37	13·96	8·36	3·30	3·26	13·10	2·38	·77	trace	·17	18·22
Total thickness	13	6	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

the average yield of the ore passed through the furnaces is only about 27 or 28 per cent. of iron. This low yield is compensated by the ease with which the ore is wrought, and the fact that the furnaces for smelting it have been built on the spot. The high percentage of carbonate of lime throughout the greater part of the bed is very conspicuous, much of it being probably due to the large number of shells in the ore; but it also exists apart from these, and in a mechanical condition, too, as some of the poorer brown ore where shells are absent effervesce very briskly when wetted with acid. The best ore does not so effervesce. On account of the excess of lime, the ore generally has to be mixed in the furnace with about 5 or 6 per cent. of silicious ore from Mid-Lincolnshire. Beds A and B in the above analyses, it will be seen, are much higher in silica than any of the others. This is probably owing to some of the overlying sand having found its way into the numerous crevices which exist in A and B, especially in the former, but the sand would separate itself naturally from the ore in the process of working, so that the yield of iron in these two parts of the bed, as they reach the furnaces, is probably 5 per cent. higher than is shown in the above analyses, and the silica proportionately less.

The average of eleven analyses gives the following as the percentage weights of the more important earths, etc., contained in the ore :—

	Average.	Extremes of Variation.
Silica	11·78 ...	5·55 to 24·40
Alumina	4·68 ...	3·30 „ 6·62
Lime	9·51 ...	1·79 „ 13·93
Magnesia	1·66 ...	·58 „ 3·02

Below is an analysis of one of the greenish kernels which are found amid the brown ore :—

Water at 212° Fahr.	5·31
Combined water and organic matter	5·31
Peroxide of iron	12·87
Protoxide of iron	14·83
Oxides of alumina and magnesia	4·89
Lime	20·78

Magnesia	2·26
Phosphoric acid	1·00
Carbonic "	23·82
Sulphuric "	trace
Bisulphide of iron	·26
Insoluble silicious matter	8·67
Total	100·00
Metallic iron	20·68

Some of these green kernels yield above 30 per cent. of metallic iron, others less than 20 per cent. They also contain a considerable quantity of carbonate of lime, much of which seems to be in mechanical combination, as the ore, when treated with acid, effervesces freely.

The average specific gravity of the brown ore is about 2·8, but it is very porous, as shown by the fact that it absorbs from 15 to 30 per cent. of its volume of water, even when in an air-dried condition. The great practical importance of this fact will be better appreciated, when it is stated that in dry weather a ton of iron can be made with 5 cwt. less ore than is requisite in wet weather.

Deposits in the Middle Lias.

More ore is raised in the United Kingdom from this formation than from any other. It all comes from one geological horizon, the "rock bed" or upper part of the middle lias, and most of it from one locality—Cleveland. The description will therefore begin with that district.

Cleveland. The development of the Lias here is partly shown in Plate II. (Section N. Yorkshire), but it will be better understood with the help of the following general section:—

Dogger Series (Inferior Oolite).

		Ft.	in.	
Upper Lias	Shale with cement-stone nodules (alum-shale series) ...	115	0	A. communis.
	Shale with dogger (jet rock series)	48	0	A. serpentinus.
	Grey shale with doggers ...	30	0	A. annulatus.

		ft.	in.	
Middle Lias	**Ironstone** (main seam) ...	11	6	A. spinatus.
	Shale, with doggers	10	6	
	Ironstone (bottom seam) ...	2	9	A. margaritatus.
	Shale with nodules of clay ironstone	20	0	
	Ironstone in thin bands ...	1	9	
	Shale with ferruginous doggers	30	0	
	Sandstone, sometimes flaggy, calcareous, and ferruginous	40	0	
Lower Lias	Shales, with numerous thin limestones in the lowest 300 feet	700	0	A. capricornus, Jamesoni, armatus, oxynotus, Bucklandi, angulatus, and planorbis.

In dividing this section into Upper, Middle, and Lower Lias, lithological characters have been considered, rather than palæontological, as being more useful in practice.

The main seam of ironstone is the only one that has been wrought extensively, though a lower seam has been wrought in one part of the district. The main seam is known to extend over a very large area, probably exceeding 350 square miles; but the area over which it can be profitably worked, at least for many years to come, is much less than this, probably not a fifth of it, and may be said to lie mainly within the area north of an east and west line (magnetic) passing through Kildale; though at Grosmont, outside that area, a considerable quantity of ore has also been raised. That, however, came only in part from the main seam, and partly from another and lower seam. The main seam, as far as is known, may approximately be said to lie within a triangle, having one of its angles at Redcar, another at Robin Hood's Bay, and the third at Thirsk.

The general dip of the bed and of the strata in which it occurs is to the south-east, at a low angle, about 1 in 15, perhaps, on an average; but there are numerous variations and even reversals, where the rocks are thrown into gentle undulations or are disturbed by faults.

Except at its outcrop, the bed throughout its known area is covered by the upper lias, and for a great part of that area by the inferior oolite as well.

The outcrop of the ore bed is, as a rule, narrow. The contracted width is owing to the general steepness of the ground where the bed comes to the surface, a rather striking feature in the physical geography of Cleveland; which arises partly from the comparatively soft shales of the upper lias being covered, and therefore to some extent protected from denudation, by the harder sandstones of the lower estuarine series, and partly from the fact that the ore is *underlain* as well as *overlain* by soft shale.

In consequence of the narrowness of the outcrop very little of the ore has been worked "opencast." The bulk of it, therefore, has had to be mined. Some of it, as at Eston and Upleatham, etc., has been worked by inclined drifts from the outcrop. In other cases shafts have been sunk, and some of them are of considerable depth; one, put down a few years ago at Lumpsey, being over 600 feet. The North Skelton pit is upwards of 740 feet, and the Kilton pit is about 680 feet.

The thickest, and perhaps the best, part of the bed is along its outcrop by Normanby, Eston, and Upleatham, whence it becomes gradually reduced in thickness towards the south-east, until a line passing from Roseberry and Lofthouse is reached. Along that line a thin shale appears near the middle of the ore. This shale increases, and the two beds of ore diminish in thickness on to a line between Kildale and Runswick, where, perhaps, the limit of the workable bed is reached; at least, it is very unlikely that it will be worked on the south-east side of this line, except in times of high prices, until it has been nearly exhausted on the north-west, which certainly will not be for a great many years. The reduction in the thickness of the ore and the increase of that of the intervening shale in a south-easterly direction will perhaps be best understood by reference to the diagrammatic section on Plate IV. (p. 256), extending from Eston to Grosmont. It will there be seen that the bed becomes more and more split up by shale on the south-east, until at Grosmont it is scarcely recognisable. Accompanying the expansion of the intervening shales is a deterioration in the quality of most of the ore, so that at Grosmont

only the lowest part of the main bed, as developed at Eston, is workable. This part is called, at Grosmont, the *Pecten* seam. About 30 feet below this there is another seam called the *Avicula* seam, which has also been worked at Grosmont; but it is not, at present, of any value in the district where the main seam is best, that is in Cleveland.

Examined in detail, along its north-east outcrop, at Eston and Upleatham, the main seam yields the sections given below.

		Eston.		Upleatham.	
	Grey shale and ferruginous nodules (roof).				
A.	**Ironstone** (top block) in alternate hard and soft layers (not worked)	3	2	... 3	0
B.	**Ironstone** (main block)	12	0	... 10	0
C.	„ (bottom block, not worked) ...	1	10	... 2	0
	Shale (sole).				

The alternately hard and soft layers in the top block A. are very variable, as may be seen from the following detailed measurements of them at different places along the outcrop:—

Eston Old Bank.

	Ft.	in.
Hard ore band	0	11
Softer laminated ore	0	1
Hard ore band	0	2
Softer laminated ore	0	0¾
Hard ore band	0	3
Softer laminated ore	0	1½
Hard ore band	0	2¾
Softer laminated ore	0	1¼
Hard ore band	0	3½
Softer laminated ore	0	3¼
Hard ore band	0	2¼
*Softer laminated ore ...	0	2
Hard ore band	0	1½
*Softer laminated ore ...	0	2
Total ...	3	2

Eston Junction.

	Ft.	in.
Hard ore band	1	1½
Softer laminated ore	0	1½
Hard ore band	0	3
Softer laminated ore	0	2¾
Hard ore band	1	1
*Softer laminated ore ...	0	3½
Total ...	3	1¼

Hobb Hill.

	Ft.	in.
Softer laminated ore	0	5
Hard ore band	0	4
Softer laminated ore	0	1½
Hard ore band	0	4½
Softer laminated ore	0	1½
Hard ore band	0	5½
*Softer laminated ore ...	1	0½
Total ...	2	10½

The bands marked thus * frequently contain a large quantity of bisulphide of iron, and are consequently known as sulphur bands. They have been largely used as a substitute for pyrite in the chemical works at Washington and Middlesborough. The hard ore bands, at the outcrop at least, are frequently in a concretionary condition, and often look like lines of doggers.

In Skinningrove and Slapewath mines, nearly on the dip side of the best part of the bed, the following sections are obtained:—

		Skinningrove.	Slapewath.
	Shale (roof).		
		In. In.	In. In.
A	**Ironstone** (top dogger) left on in working	3 to 6 ...	1 to 6
B	**Ironstone**	4 „ 0 ...	3 „ 0
B	„ (middle dogger) hard and not drilled in working	1 „ 6 ...	1 „ 11
B	„	4 „ 0 ...	4 „ 1
	Shale. Hard green, with bands of ferruginous doggers.		

On the south-east side of the first line above mentioned, the middle dogger, at Slapewath and Skinningrove, is partly replaced by shale, as seen in the section below, of the old Hutton mines (after Marley):—

		Ft.	In.
	Ironstone	1	4
A (Left on in working.)	„ mixed with shale	1	2
	Sulphur-band	0	2
	Ironstone	0	2½
	Sulphur-band	0	2
B	**Ironstone**	3	5
	„ very shaly	0	5
	„	2	8
	Shale, with bands of ferruginous dogger ...	4	6
C	**Ironstone**	1	0
	Shale	0	2
	Ironstone	1	6
	Shale (sole).		

Dipward from the strike line through Old Hutton mines the ironstones diminish, and the shale between them thickens gradually towards the south-east, so that along the second line

named a section something like the following at Kildale occurs:—

		Ft.	In.
A	**Ironstone** ...	0	11
	" very shaly	1	1
	Sulphur-band	0	6
B	**Ironstone** ...	2	6
	Shale	1	3
	Ironstone ...	1	7
	Shale, with ferruginous bands ...	2	7
C	**Ironstone** ...	2	6
	Shale (sole).		

At Grosmont the section is as follows:—

			Ft.	In.	
Main Seam of Cleveland.		**Ironstone**, limy	0	6	A. and B.
		Shale	3	6	
		Ironstone, limy	0	4	
		Shale	2	0	
		Ironstone, limy	0	10	
		Shale	3	1	
		Ironstone, limy	1	8	
		Shale, sandy	4	4	
		Ironstone, limy	0	6	
		Shale, sandy	3	10	
		Ironstone, limy	0	6	
		Shale, sandy	1	7	
		Dogger band	0	6	
		Blue grey shale, sandy ...	4	0	
	Pecten Seam.	**Ironstone** ...	1	0	C.
		Black shale	1	6	
		Ironstone ...	2	0	
		Greyish sandy shale	4	0	
		Ironstone, limy	1	0	
		Shale	22	0	
	Avicula Seam.	**Ironstone** ...	1	0	
		Shale	0	4	
		Ironstone ...	2	5	
		Shale			

Speaking generally, the ore, except the top block, is thick bedded, and intersected by two sets of vertical joints. Its prevailing colour, where covered by the upper Lias, is bluish-grey. Towards the base it becomes somewhat greenish, and

the bottom block C. is a dark greenish-grey. Along the outcrop the bed is mostly altered to a hydrated peroxide, and the colour is snuff-brown, except when there still remain a few greyish or greenish-grey cores of the carbonate. These cores are very few and small where the bed is uncovered, but increase in. size and number as the unaltered part of the bed is approached. The distance to which the brown ore extends inwards depends upon the thickness of the cover. At Eston, for instance, where the ground is very steep above the outcrop, and the upper Lias consequently soon attains a considerable thickness, the brown ore does not extend many yards in from "day." But at Kirkleatham and Hobb Hill, where the cover has been mostly removed by denudation, the belt of brown ore is much wider.

The ore in places is oolitic; but much of it does not exhibit that structure, having simply the appearance of a mud stone.

Organic remains are abundant, being almost crowded in places. According to Tate and Blake,[1] ninety-five different species have been met with. The following is a list of the more common forms :—

A. spinatus.
Belemnites breviformis.
„ paxillosus.
Pitonillus turbinatus.
Crytema consobrina.
Ostrea submargaritacea.
Pholadomya ambigua.
Astarte striato-sulcata.
Waldheimia resupinata.
Terebratula punctata.
Pecten æquivalvis.
„ lunularis.
Monotis cygnipes.
Macrodon liasinus.
Gresslya intermedia.

[1] Yorkshire Lias.

Pleuromya rostrata.
Arcomya arcacea.
Rhynchonella capitulata.
„ tetrahedra.
„ lineata.

As in the Frodingham deposit, the shells generally retain their original limy nature, but in some of them carbonate of iron has taken the place of the lime. This fact was first pointed out by Sorby [1] thirty years ago.

The specific gravity of the blue-grey mudstone-like ore is about 2·8, and of the greenish-grey oolitic ore 3. The former absorbs water to the extent of about 10 per cent. of its volume, and the latter in some cases to as much as 26 per cent.

Except at the outcrop, the ore is a carbonate with a small admixture of magnetic oxide. Its quality in different parts of the bed at Eston is shown by the analyses on next page.

The seam is not only thickest here—at Eston—but it seems also to be richest in iron. The composition of the different workable parts of the bed at the old Hutton Mines is given in the following analyses, which do not vary greatly from those of corresponding parts of the seam at, for example, Slapewath and Lofthouse :—

Division of Seam.	Thickness.	Metallic Iron.	Peroxide of Iron.	Protoxide of Iron.	Silica.	Alumina.	Lime.	Magnesia.	Sulphuric Acid.	Phosphoric Acid.	Carbonic Acid.	Water.
	Ft. in.											
B	3 5	28·84	1·70	35·55	20·90	3·79	4·20	1·12	trace	2·66	25·18	4·90
B	2 8	27·45	1·80	35·75	15·65	4·95	7·39	2·98	0·07	3·05	23·47	4·89

At Grosmont, parts A and B of the main seam, as developed at Eston and Hutton, are unworkable, but C, known at Gros-

[1] *Proceedings of the Geological and Polytechnical Society, West Riding, Yorkshire*, 1856-7.

Divisions of Seam.	Thickness. Ft. in.	Metallic Iron.	Peroxide of Iron.	Protoxide of Iron.	Silica.	Alumina.	Lime.	Magnesia.	Bisulphide of Iron.	Sulphur.	Phosphoric Acid.	Carbonic Acid.	Water.
A. Top Block ...	2 8½	32·83	3·55	39·01	10·90	10·62	1·70	3·19	—	trace	2·08	25·26	3·69
A. Sulphur Band	0 5½	—	—	9·97	10·94	8·47	·49	1·07	53·19	—	—	—	13·20
B. Main Block ...	12 0	34·54	3·95	40·85	6·00	12·66	trace	3·19	—	trace	2·49	26·16	4·70
C. Bottom Block	1 10	28·73	1·15	39·50	19·90	17·87	1·56	2·31	—	·13	2·50	5·54	9·14

mont as the Pecten seam, is worked, its composition, and that of the Avicula seam below it, being as follows:—

	Pecten seam.	Avicula seam.
Protoxide of iron	34·98	33·17
" " manganese	·48	·50
Alumina	3·20	3·92
Lime	11·96	11·90
Magnesia	4·51	4·52
Carbonic acid	29·20	28·00
Phosphoric acid	1·30	·48
Water	3·30	3·65
Ignited insoluble residue	10·04[1]	13·22[1]
Total	98·97	99·36
Metallic iron	27·21	25·80
[1] Silica	8·00[1]	9·42[1]

The Avicula seam, as shown in the section already given, is about 30 feet below the Pecten seam.

The preceding analyses are of air-dried samples, and therefore give the moisture less, and the other constituents more, than if they had come direct from the bed.

The average metallic yield of Cleveland ore (main seam) is about 30 per cent., and the proportions of its four most abundant earthy constituents, as given by the average of 18 analyses of the ore as it occurs in the bed, are as under:—

	Silica.	Alumina.	Lime.	Magnesia.
Average	11·42	8·63	5·13	2·99
Variations	7·17—20·90	3·79—13·53	3·80—7·77	1·12—5·21

Caythorpe, Lincolnshire. This deposit[2] is by many considered to be on the same geological horizon as the Frodingham ore; and if the general appearance of the bed, as seen from a little distance, were alone considered, this opinion would more frequently prevail, for the ore has exactly the thin-

[1] See Marley, *Transactions of the North of England Institute of Mining and Mechanical Engineers*, vol. v.

[2] Said to be in Lower Lias in Hunt's "British Mining."

bedded flaggy appearance of the Frodingham ore, which is altogether unlike the thick-bedded "blocky" arrangement of other ironstones in the rock bed, as, for instance, those of Cleveland, Holwell in Leicestershire, or Fawler in Oxfordshire. But when the fossil contents of the bed at Caythorpe are examined, all doubt about its belonging to the middle lias at once disappears, for crowds of *Rhynchonella tetrahedra* and *Terebratula punctata* are met with in almost every part of the bed. Most of the former shells are hollow, and lined with crystals of calcite.

The bed has a slight dip to the south-east, and crops out along the level ground lying to the east of the village of Caythorpe. The working of the ore is confined at present entirely to the outcrop adjoining the Great Northern Railway, where the ore is covered by sand (with small pebbles), varying in thickness from 3 to 7 feet. The greatest thickness of ore yet exposed is 10 feet, that is near the railway. From there it becomes gradually thinner to the village of Caythorpe, where it is only about 3 feet thick. Working operations, therefore, stop some distance short of Caythorpe.

The ore has a prevailing yellowish colour, but is traversed at irregular intervals by dark brown bands up to ½ inch wide. This latter part of the ore is much denser than the other, and the bands are in some cases so disposed as to produce a concretionary appearance. As already mentioned, the ore is thin bedded, and in parts oblique lamination is very frequent.

Speaking generally, the bed is harder and more compact towards the base than it is in the upper part, and it gets gradually harder throughout towards the railway, that is, towards the south-east, as if the Upper Lias clay was not far off. Towards the "rise" the bed contains a few roughly lenticular pieces of grey limy rock, which graduate into the ore. They are very full of fossil shells, and vary in size from 2 to 10 inches in thickness, and from 2 to 4 feet in length. Dipwards they increase in size and frequency, but are everywhere most common in the lower part of the ore, and give it a very bedded appearance. In working on the dip side of the outcrop the ore frequently comes off in large flag-like flakes, sometimes as much

as 4 feet in area, and perhaps not more than 6 inches thick at the thickest part.

Besides the limy cores there are also grey and green cores of earthy carbonate of iron, similar to those described in connection with the Frodingham and Cleveland ores. These occur mainly in the low part of the bed, and towards the dip, very few being met with in the "rise" part of the bed, where the alteration has proceeded further.

Below the ore there are about 3 feet of ferruginous limestone, and under that blue clay.

The yellow part of the ore is oolitic in places, and so is the included and underlying limestone, but the brown ore is only slightly so.

The average specific gravity of the brown ore is about 2·5, but it is very porous, absorbing water to the extent of 10 to 21 per cent. of its bulk. Its average composition is perhaps fairly expressed by the following analysis :—

Water at 212° Fahr.	4·330
" combined	10·030
Peroxide of iron	47·430
Oxides of alumina and manganese	10·007
Lime	7·840
Magnesia	·580
Phosphoric acid	·403
Sulphuric "	trace
Carbonic "	6·960
Insoluble silicious matter	12·260
Total	99·840
Metallic iron	33·20

The lime which occurs in the ore is probably as a carbonate, and in a mechanical condition, as the ore effervesces when wetted with acid; in some places only slightly, but in others briskly. The quantity of water lost at 212° Fahr. in the preceding analysis is probably 8 or 10 per cent. less than the ore contains *in situ*, and as it is sent to the market, as the specimen from which the analysis was made had been in the writer's

possession at least twelve months before being analysed. The metallic yield of the ore as raised will therefore be about 30 or 31 per cent.

Holwell, etc., Leicestershire. At Holwell, about three miles north of Melton Mowbray, and at Eastwell, about three miles north-east of Holwell, as well as at Waltham and Wartnaby, the Marlstone rock-bed has recently been largely worked for iron ore.

The Holwell workings, which may be taken as typical of all in the neighbourhood, are close to the village of Holwell, but on the opposite side of the small valley, which lies on the east of the village. A section of the beds seen there is as below:—

	Ft.	in.
Blue clay (Upper Lias).		
Ironstone	12	6
Ferruginous limestone locally called "Sandrock"	20	0
Grey shaly clay.		

The rocks have a gentle inclination to the south-east.

The working of the ore is confined mainly to its outcrop where the Upper Lias is off, although at one point it has been worked where overlain by about 6 feet of clay belonging to that formation. The ore, however, became very hard as the thickness of the cover increased. This, combined with the extra cost of "baring," put a stop to further operations in that direction.

The outward appearance of the ore bed is very much like that of Cleveland at the outcrop. It is thick bedded, and intersected by two sets of vertical joints. Many of these are several inches wide, and filled with a yellowish-grey clay, which has evidently been washed down from the overlying drift. There are also a number of less persistent joints of a lenticular form, some of which are as much as three inches wide, but they seldom exceed a foot or two in length. They occur both vertically and along the bed planes. Cases of false bedding are not infrequent, and in some places the ore is quite soft and sandy, so that it may be easily crumbled between the fingers. These sandy places occur along the bed planes, and have a

roughly lenticular form. They are somewhat numerous, and very irregular in their disposition in the bed. The ore, where worked—that is, at the outcrop—is a hydrated peroxide, and has a prevailing yellow or yellowish-brown colour; but it contains a few kernels of green carbonate and some pieces of greyish or greenish-grey ferruginous limestone, which increase in size and number towards the dip. The yellowish-brown ore adjacent to the green kernels is invariably concretionary, lighter and darker-coloured bands alternating. This structure is also seen in other parts of the bed where the cores are yellow. These are, however, not abundant.

Adjacent to joints, whether vertical or horizontal, the ore is almost always darker and more compact than it is where joints are absent, and is of the same character as the darker bands of the concretions. As a rule, the yellow ore is oolitic, but in places it has the character of a mudstone. The dark brown ore is but slightly oolitic.

Organic remains are abundant, both in the ore and in the pieces of enclosed limestone, or sand-rock, as it is locally called, and many of them are in a fragmentary condition. The common species are of *Belemnites*, *Terebratulæ*, and *Rhynchonellæ*.

The average specific gravity of the ore is about 2·5, and it is very porous, absorbing water in quantities varying from about 12 to 27 per cent. of its bulk. The composition of the yellowish-brown ore is shown by the following analysis of a specimen which had been in the writer's possession about twelve months before being analysed, and therefore, like the sample from Caythorpe, gives less hygroscopic water, and consequently a higher metallic yield than the ore will contain in the bed.

Water at 212° Fahr.	5·360
„ combined	11·240
Peroxide of iron	50·570
Protoxide „ „	·570
Oxides of alumina and manganese...	9·935
Lime	3·960
Magnesia	1·171

Phosphoric acid	1·925
Sulphuric "	trace
Carbonic "	1·860
Insoluble silicious matter	12·540
Total	99·131
Metallic iron	35·80

Much of the ore is not so rich as this. The poorer qualities effervesce when wetted with acid, the better ore does not, except where fossil shells are present.

Adderbury and Fawler, Oxfordshire. On the north-east border of Oxfordshire a considerable quantity of ore has been obtained from the "rock-bed" at Adderbury, and some from King's Sutton in the adjoining county of Northamptonshire, but operations are suspended at both places for the present. At Fawler, in Mid-Oxfordshire, ore is still being obtained from this horizon. When first worked it was got by open working; but since the recommencement of operations, a few years ago, it has been mined. The rocks associated with the ironstone are shown in the following section:—

		Ft.	in.
Rubbly limestone (inferior oolite)		12	0
Blue clay	Upper Lias	7	0
Yellowish-grey clay	Upper Lias	2	0
Ironstone		8	0
" brown, concretionary with green cores		5	0
Sand.			

The ore crops out in the side of the valley of the Evenlode. It is thick bedded, and intersected by two sets of vertical joints like that at Holwell. Some of the vertical joints are very wide, and are filled with yellowish clay from the overlying bed of that material.

The ore is mainly a hydrated peroxide or limonite, and its colour is partly yellow and partly brown, not only at the outcrop, but also below the upper lias as far as they have yet worked. From the nearer outcrop (the north-east) the faces are probably not more than 70 yards, though they are

much farther from the south-west outcrop. The brown ore is much denser than the yellow, but it only occurs in thin bands or "shells," as at Caythorpe and Holwell. The yellow ore is oolitic, the brown is not. There is almost a complete absence of grey or greenish cores in the upper 8 feet of the bed, but they are abundant in the lower part, and some of them are very large, for which reason this part of the bed is not worked.

The average specific gravity of the ore is about 2·5. Like other ores from the same geological horizon it is very porous, absorbing water to the extent of 18 to 27 per cent. of its bulk. Its composition may be gathered from the following analyses :—

	No. 1.	No. 2.
Protoxide of iron	1·04	·86
Peroxide " "	46·93	44·67
Manganese oxide	·51	·44
Alumina	7·86	9·10
Silica	10·55	12·34
Lime	11·79	9·29
Magnesia	1·12	·66
Phosphoric acid	·66	·55
Sulphuric "	trace	trace
Carbonic "	8·55	6·11
Water	10·15	16·31
Total	99·16	100·33
Metallic iron	33·66	31·94

No. 1 gives the result of a sample dried at 212° Fahr.; No. 2 of the ore partly air-dried.

The ore effervesces in places when wetted with acid; in other parts it does not.

Deposits in the Lower Oolite.

The next ferruginous zone of importance is at the base of the inferior oolite, immediately succeeding the upper lias, as shown in Plate II. It exists over a very large area, and has been extensively wrought in Yorkshire, Lincolnshire, Rutlandshire, and Northamptonshire, though with very different results, as will appear from the detailed descriptions following.

North Yorkshire. In the greater part of this district the ore which occurs in the horizon now reached is not of much value commercially. It is known in Cleveland as the "top seam," and to outsiders mainly as the "dogger series." Since the discovery of the main seam (in the middle lias) in Cleveland, the "top seam" has in that district been almost entirely neglected, owing to its great inferiority; in fact, over a considerable part of Cleveland it is unworkable profitably under almost any circumstances. Generally, it may be said to increase in thickness towards the south-east, at least for a considerable distance, which is the reverse of the main seam; then it decreases in that direction. Along the Eston and Upleatham range it is practically non-existent.

In some of the sinkings that have been made to the south-east of Guisborough, through the lower oolitic rocks to the main seam, it is only a few inches thick. At Rosedale, on the coast between Straiths and Runswick Bay, it presents the following section:—

	Ft.	in.	Ft.	in.
Blue shale (roof).				
Ironstone nodules	0	3		
Blue shale	2	2		
Ironstone	4	4 —	6	9
Shale (sole).				

A few miles further south, at Goathland, the seam is larger still, as shown by the section below:—

	Ft.	in.	Ft.	in.
Sandstone (roof).				
Ironstone, silicious	10	6		
Sandstone, ferruginous	1	2 —	11	8
Shale (sole).				

On the opposite side of the district, at Feliskirk, three miles north-east of Thirsk, the seam is about 7 feet thick. From Goathland to Feliskirk, as pointed out by Professor Phillips thirty-nine years ago, is the line along which the dogger series "receives its maximum dose of iron," and from this line it grows gradually poorer, both towards the north-west and south-east. It will be noticed that it is thinner on the west than on

the east; but, as mentioned by the authority just named, there appears to be a general thinning of the lower oolitic rocks in that direction.

The seam has often been tried at Grosmont and elsewhere in the same neighbourhood, but it has always been found to contain too much silica for metallurgical purposes. The only locality where it has been worked at all extensively in the area now under consideration is in the valley of Rosedale. The dogger series there comes to the surface, in a narrow strip along the steep sides of the valley. Except at the outcrop it is overlain by a variable thickness of shales and sandstones belonging to the lower estuarine series.

The seam is known in Rosedale as "the seam of the district." It dips to the south at about 1 in 22. As already mentioned, the outcrop is narrow, so that comparatively little ore has been worked by opencast, although in 1873 and 1874 a quantity of ore was worked in this way; the quality, however, was very poor. The same class of ore is now used on a small scale for road metalling. At the present time operations are confined to the eastern side of the valley, at what is known as Rosedale East mines. The seam has also been worked at Sheriff pit, and in the neighbourhood of the magnetic quarry. These latter mines are called Rosedale West mines. A few years ago some ore occupying the same horizon was also worked in the adjoining valley of Farndale.

On the west side of the valley, just opposite the village of Rosedale, the section of the seam is as follows:—

		Ft.	in.
	Yellow shale (roof).		
A.	**Ferruginous sandstone**	1	11
	Dark sulphury shale	1	3
	Greenish sandy "		6
	Dark shale		6
B.	**Ironstone**	8	0
	Shale (sole).		

Near Sheriff pit it is, according to Marley, as shown on next page.

		Ft.	in.
	Freestone (roof).		
A.	**Sandy ironstone**	10	0
	Shale	8	0
B.	**Soft brown ironstone**		6
	Strong " "	3	3
	Blue-grey "	4	0
	Brown and blue stone	5	3

On the opposite side of the valley, at Bell End, the seam is developed thus :—

		Ft.	in.
	Shale (roof).		
A.	**Ironstone**	3	0
	Grey shale	2	0
B.	**Ironstone**	4	3
	" concretionary	1	6
	" compact	2	0
	" inferior	4	0
	Sandstone shaly (sole).		

Both A. and B. have been worked at the outcrop, but B. only has been "mined" on account of its superior quality. At Rosedale East mines the workable height of the seam varies from 5 feet to 9 feet 6 inches, the average probably being about 6 feet 6 inches. At Sheriff pit the average, according to Mr. Charles Parkin, is about 5 feet 10 inches.

The ore is thick bedded, and at the outcrop is a hydrated peroxide of a yellowish-brown colour; but as the thickness of the cover increases rapidly, the oxide soon gives way to a carbonate, and the brownish colour changes to a greeny-grey.

The ore is very oolitic both in the weathered and unweathered parts of the bed. Its chemical qualities are indicated by the following analyses :—

	Sheriff's Pit (Greeny-grey ore).	Rosedale East Mine (Greeny-grey ore).
Peroxide of iron	17·92	26·57
Protoxide of iron	28·67	18·19
Silica	10·80	18·55
Alumina	8·52	9·84
Lime	4·97	6·24
Magnesia	3·16	2·91
Phosphoric acid	2·00	1·43
Sulphuric "	·10	·03

	Sheriff's Pit (Greeny-grey ore).	Rosedale East Mine (Greeny-grey ore).
Carbonic „	19·00	11·30
Water	4·50	4·80
Total	99·64	99·86
Metallic iron	34·74	32·64

The metallic yield of the ore, as it occurs in the bed, is probably 2 or 3 per cent. less than in these analyses. It will be noticed that there is a considerable proportion of peroxide along with the protoxide of iron, which is suggestive of the ore being magnetic. It is found, however, that even in large masses it does not generally affect the magnetic needle, nor is it attracted by the horse-shoe magnet. But if a number of oolitic grains be extracted from the matrix and placed within the influence of a magnet they are at once attracted by it. If, further, a thin slice of stone be placed under the microscope, it is at once seen that the oolitic grains consist partially of magnetite arranged generally in irregular concentric rings.

The average specific gravity of the greeny-grey ore is about 2·9, and of the brown ore from the outcrop 2·7. Their respective porosities are about 16 and 27 per cent. of their bulk.

The following list of fossils from the "dogger" is given by Mr. W. H. Hudleston,[1] many of which he found had been converted into carbonate of iron :—

Natica adducta, Phill.
Chemnitzia lineata, Sow.
„ sp.
Nerinæa cingenda, Phill.
Certhium (two specimens).
Alaria Phillipsii.
„ sp.
Littorina punctura, Bean.
Trochus pyramidatus, Phill.
Nerita lævigata, Phill.
Trochotoma sp. n.

[1] *Proceedings of the Geological Association*, 1876.

Acteonina.
Rhynchonella obsoleta, Sow.
Terebratula perovalis (?), Sow.
Hinnites vellatus (?), Gold.
Gervillia tortuosa, Phill.
„ lata, Phill.
Pteroperna striata, Bean M.S.
Modiola cuneata, Sow.
Cucullæa cancellata, Phill.
Microdon Hirsonensis, d'Arch.
Trigonia denticulata, Ag.
„ V. costata, Lyc.
„ spinulosa, Y. and B.
„ sp.
Cardium acutangulum, Phill.
„ striatulum, Phill.
Tancredia axiniformis, Phill.
Astarte elegans, Sow.
Opis Phillipsii, Mor.
Ceromya Bajociana, Sow., vel concentrica, Sow.
Gresslya adducta, Phill.

Rosedale magnetic ore. Besides the bed just described, there is, in Rosedale, a most remarkable deposit of magnetic iron ore, which has given rise to several papers and discussions,[1] in which were developed great differences of opinion among the various persons engaged therein. The deposit, or deposits —for there are really two—occur just under the seam, known as "the seam of the district," in two approximately parallel troughs, between five and six acres in extent, in the upper lias shale, as shown in Fig. 22; the plan represents them as they would appear if the sandstones and shales of the lower estuarine series were removed.

At first the deposits were quarried; but as the "overburden" increased, mining was resorted to, and the deposits have now been almost exhausted in this way.

[1] *Transactions North of England Institute of Mining and Mechanical Engineers*, vols. vi., vii., and xix.

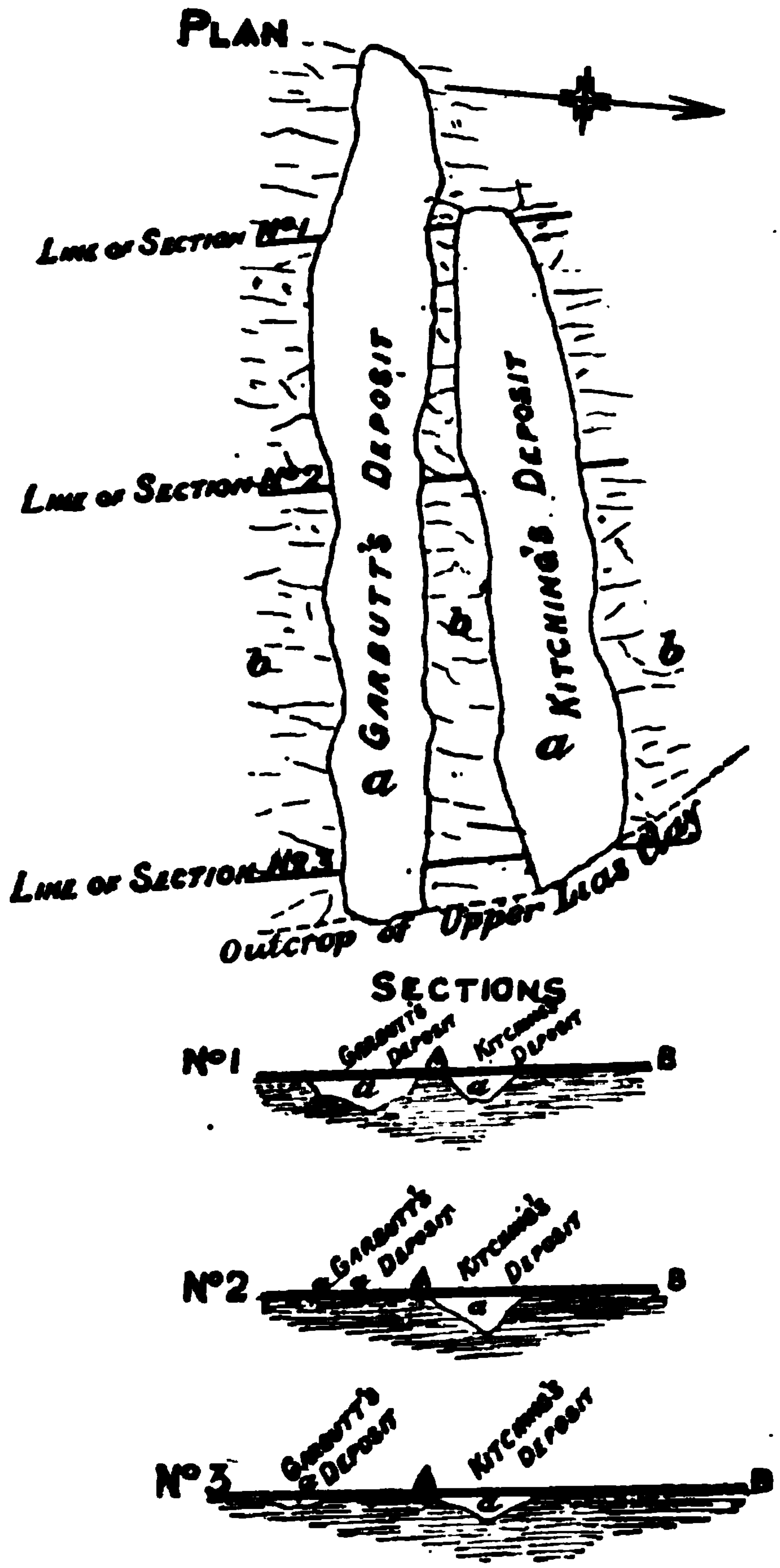


FIG. 22.—PLAN AND SECTIONS OF ROSEDALE MAGNETIC ORE DEPOSIT (Scale 660 feet to an inch).

References—*A* Shales and Sandstones (Lower Estuarine Series). *B* Iron Ore "the Seam of the District" (Dogger Series). *a* Magnetic Ore. *b* Blue Clay (Upper Lias).

Neither Garbutt's nor Kitchen's deposit has been known to yield any organic remains, so that there is a difficulty in fixing their age; but they seem, on stratigraphical considerations, to be the equivalent of the Blae Wyke sands, and to have been formed on an eroded surface of the upper lias. Small denuded areas of this character are not uncommon in the upper lias of Yorkshire, as well as of other districts. In Yorkshire they are frequently occupied by silicious limestone belonging to the dogger series; especially is this so at Bilsdale.

At the outcrop the ore was very much broken up by weathering, and much of it had a concretionary form. The kernels, which in some cases were as much as four feet in diameter, were of a bluish-black in the centre, but became paler towards the outside, and the surrounding rings were brown. As the cover increased, the results of weathering mostly disappeared, and the ore became much more compact, and had everywhere the blue-black colour of the interior of the kernels found at the outcrop, except along the sides of the stronger joints, where a brown band an inch or so wide might exist.

The ore is very oolitic, and where unweathered is strongly magnetic. Its chemical composition is shown by the following analyses. No. 1 is of blue-black ore, and No. 2 of the brown altered ore found along strong joints or on the outside of the kernels.

	No. 1.	No. 2.
Water at 212° Fahr.	·33	14·40
" combined	3·39	
Peroxide of iron	27·71	64·05
Protoxide "	36·77	—
Oxides of alumina and manganese	9·72	11·45
Lime	·96	1·15
Magnesia	1·13	·72
Phosphoric acid	·89	—
Sulphuric "	trace	—
Carbonic "	9·12	trace
Insoluble silicious matter	9·52	9·20
Total	99·54	100·97
Metallic iron	48·00	44·83

The specimens analysed were air-dried, so that the water should be increased in No. 1 about 10 per cent., and the metallic iron should be reduced 4¼ per cent., probably, to arrive at the composition of the ore in its natural condition. With these alterations No. 1 may be fairly taken as an average.

It appears from analysis No. 1 that the ore is not a true magnetite, but a compound of magnetite and clay ironstone, the proportions of the different compounds of iron being in all probability as below:—

FeO.		No. 1.
12·45	+ Fe_2O_3 27·71	= 40·16 Magnetite.
14·92	+ CO_2 9·12	= 24·04 Carbonate of iron.
9·40	existing probably in other combinations.	
36·77		

A physical analysis confirms these results. If the ore be examined in a thin slice under the microscope, it is seen that the magnetite resides entirely in the oolitic grains, and mainly in the interior of them in a concretionary form, the quantity in the different grains being very variable.

The specific gravity of the blue-black ore, of which analysis No. 1 shows the composition, is 3·8, and its absorptive capacity, in an air-dried condition, is 15 per cent. of its bulk.

Mid-Lincolnshire. Just east of the city of Lincoln, and on the north side of the valley of the Witham, at Greetwell and Monk's Abbey, a bed of ore, at the base of the inferior oolite, has been worked somewhat extensively. It has also been worked on the opposite side of the Witham, east of Canwick, as well as at Waddington and Coleby, a few miles further south along the cliff. In Hunt's "British Mining" this deposit is wrongly stated to be on the lower lias.

The ore crops out on both sides of the valley of the Witham, and as the inclination of much of the ground at the outcrop is very gentle, a considerable quantity of ore has been got by open working. Where the cover was too thick for this to be done profitably, mining has been resorted to.

The general dip of the ore bed (and its accompanying rocks) is to the east, at about 1 in 60. Its greatest known

thickness is 11¾ feet, and the least, where worked, 5 feet, although it has been proved by boring to be only 3 feet thick in places. The average thickness is probably about 9 feet. A section of the "face" of part of one of the open-cuts on the north side of the Witham is given below:—

	Ft.	in.
Lincolnshire limestone, very much broken and disturbed	8	0
Lincolnshire limestone, compact	7	0
Grey shale	1	0
Iron Ore	10	0
Blue clay (upper lias).		

The ore at the outcrop generally is a brown and yellow hydrated peroxide, very concretionary, and in places very cellular. The concretions generally have kernels of soft, yellow ore, but near the base of the bed there are a few greenish and greyish kernels. These consist of carbonate of iron. The ore surrounding the kernels is alternately dark brown and yellow, the dark brown layers being much harder and denser than those that are yellow, and as a rule are much thinner, seldom exceeding ¼ in. or ⅜ in. in thickness. The yellow, green, and grey ores are very oolitic, but the brown ore is only partially so. The proportions of the two classes of ore are very variable; but the largest quantity of the brown kind occurs where the bed has been most weathered—that is, where the cover is least. Thence it becomes less and less in proportion to the yellow ore as the thickness of the overlying rocks increases. It is probably very near the mark to say that on the average there is, by weight, 20 per cent. of brown ore, and 80 per cent. of yellow ore, or by volume 14 per cent. of brown, and 86 per cent. of yellow. The form of the concretions is very variable, sometimes approaching an irregular spheroid, in other cases to a parallelopipedon. They also vary greatly in size, being least at the extreme outcrop (where they are mostly under 4 or 5 inches across); but they increase in size as the cover becomes thicker. Many of the concretions are hollow, others are not more than half filled by their cores, and there are numerous other cavities in the ore which give it quite a

rubbly and cellular appearance at the outcrop; but as the cover increases in thickness the bed becomes more and more compact, and contains a larger proportion of the green and grey carbonate. It also becomes more distinctly bedded and jointed, so that in the mine, at 200 yards from "day," the central part of the bed is, in places, almost entirely green carbonate, whilst in the upper and lower parts there are numerous green cores. The thickness of the limestone and superficial beds over the point just mentioned is about 21 feet. At 420 yards further in from "day," that is, 620 yards in all, the bed shows a still larger proportion of the green and grey carbonate, and a further consolidation of the bed. The thickness of the overlying limestone and drift, there, is 34 feet.

The underground operations have not been prosecuted beyond this point, so that it is impossible to say where the hydrated oxide disappears entirely; but it cannot be much beyond the present faces, for not far in front of them a well was sunk through the bed, and there the ore was entirely blue. Where the thickness of the cover increases more rapidly than in the case mentioned above, the change from the oxide to the carbonate, with its accompanying increase of hardness, is effected in a proportionately shorter distance.

The composition of the different parts of the bed at the outcrop, and within the mine, is as under:—

	Thickness.	Water at 212° Fahr.	Water combined.	Percxide of iron.	Oxides of alumina and manganese.	Lime.	Magnesia.	Phosphoric acid.	Sulphuric acid.	Carbonic acid.	Insoluble silicious Matter.	Metallic iron.
	Ft. in.											
At the outcrop.	4 10	15·88	9·91	51·85	4·91	1·14	0·28	1·41	0·04	0·91	13·67	36·30
	2 0	20·89	9·95	45·33	4·64	2·19	0·49	1·64	0·05	0·95	13·87	31·73
	4 2	14·52	8·20	33·47	4·56	11·14	0·45	1·13	0·04	8·24	18·25	23·43
In the mine.	5 2	14·91	10·53	54·30	3·08	1·39	0·29	1·19	0·04	1·22	13·05	38·01
	2 3	20·94	10·65	47·97	4·65	1·58	0·35	1·09	0·05	0·23	12·49	33·58
	3 11	18·99	10·90	42·50	3·72	3·35	0·35	1·57	0·05	1·84	16·73	29·75

The average yield of metallic iron from the whole bed is probably about 33 or 34 per cent. The chemical composition and the specific gravity of the different kinds of ore occurring in the bed at the outcrop are set forth in the following statement:—

Constituents.	Hard brown ore of "shells."	Soft yellow ore of cores.	Grey ore of cores.
Water at 212° Fahr.	4·65	19·63	5·36
„ combined and organic matter ...	12·31	10·88	2·05
Peroxide of iron	66·66	42·76	2·30
Protoxide „ „	—	—	39·24
Oxides of alumina and manganese ...	4·07	6·77	5·26
Lime	·87	1·02	1·87
Magnesia	·20	·40	·52
Carbonic acid	trace	trace	26·08
Phosphoric „	1·53	2·24	1·52
Sulphuric „	·03	·04	·05
Bisulphide of iron	—	—	2·58
Insoluble silicious matter	9·68	16·26	13·17
Total	100·00	100·00	100·00
Metallic iron	46·66	29·93	33·33
Specific gravity	3·3	2·3	2·6
Porosity, % of bulk	8	28	15

The whole of the analyses relating to this deposit were made soon after the samples were obtained from the mine, so that they may be looked upon as showing very nearly the composition of the ore *in situ*.

Under the microscope the hard brown ore is seen to be very compact, and in its densest part, *i.e.*, on the inside, as it occurred in the concretions, it is devoid of oolitic structure, and contains numerous small angular cavities from $\frac{1}{80}$ to $\frac{1}{1000}$ of an inch across. Some of these cavities are empty, others are filled with silica. The oolitic grains in the grey, green, and yellow cores vary from the $\frac{1}{80}$ to the $\frac{1}{100}$ of an inch in diameter. Some are solid, others hollow, but all have a concretionary structure.

Organic remains are very scarce. The writer has only seen a piece of wood, the tissue of which was replaced by hydrated peroxide of iron.

Cottesmore, Rutlandshire. The ore bed comes to the surface, here, on the western side of the rising ground, which extends in a northerly and southerly direction along by Market Overton and Cottesmore.

The general appearance of the ore corresponds very closely, both in structure and colour, with that occurring at the outcrop in Mid-Lincolnshire, the main difference being that in some parts it seems to be more weathered, and to contain a larger proportion of the dark brown concretionary rings—in fact, at and near the outcrop, it consists of almost nothing else but pieces of these rings, or "shells" which are jumbled together in a most irregular manner—the softer yellow ore having probably been washed away. The quality of the ore is thereby improved, but its mechanical condition is not so suitable for the furnace. Generally the relative quantities of brown and yellow ore are about the same as at Lincoln.

Where the ore has undergone least change by weathering, that is, where it is thickest, it is seen to be thick-bedded and to be divided by two sets of vertical joints. Some of the joints are filled with clay, which has come down from the over-lying drift. As a rule, these clay joints are only an inch or two wide, but in some cases they are as much as 12 or 18 inches across, and have been known to reach 6 feet. Where frequent, these "gulls," as they are called by the workmen, interfere greatly with the working of the ore, and a pit that was opened out not far from the present one had to be abandoned on their account. The thickness of the ore at its greatest, is about 9 feet, and it is overlaid by sand and clay belonging to the drift, to a depth of from 3 to 7 feet.

The yellow part of the ore is very oolitic, some of the cores consisting of nothing else but loose oolitic grains, which are mostly hollow, and give the ore in these parts a very sandy appearance. They, however, consist mainly of peroxide of iron, and readily become magnetic in the blowpipe flame. The

shells of these hollow oolitic concretions are about $\frac{1}{100}$ of an inch thick. There does not appear to be any green or grey cores in the deposit where it has yet been opened.

The quality of the ore may be judged from the following analysis, although, so far as metallic yield is concerned, the sample taken was better than the average by perhaps 3 per cent. Moreover, it had been in the writer's possession a considerable time, so that the metallic yield had in that way also probably been increased about 5 per cent. through the loss of hygroscopic water. The average yield of iron, as the ore occurs in the bed, is about 32 or 33 per cent.

Water at 212° Fahr.	4·68
„ combined	11·06
Peroxide of iron	57·43
Oxides of alumina and manganese	8·86
Lime	·56
Magnesia	·50
Phosphoric acid	2·24
Sulphuric „	03
Carbonic „	·66
Insoluble silicious matter	13·10
Total	99·12
Metallic iron	40·20

The specific gravity of the piece above analysed was 2·5 and its porosity 29 per cent.

Northamptonshire. The inferior oolite of this county may generally be divided into two parts, the upper consisting of sands, sandstones, and clays, with some calcareous beds, the lower, being mainly made up either of iron ore or ferruginous sandstone. The whole series is known to geologists as the Northampton sand, and near the town of Northampton it has a maximum thickness of about 70 feet, from which point it becomes gradually reduced both towards the north-east and south-west, as shown opposite.

		Towcester.		3¼ miles.	Blisworth.		4 miles.	Northampton.		21 miles.	Rockingham.		15 miles.	Stamford.	
		Ft.	in.		Ft.	in.		Ft.	in.		Ft.	in.		Ft.	in.
Northampton Sand.	Lower estuarine series	—			6	6		40	0		13	0		6	6
	Ferruginous beds ...	6	0		12	6		30	0		14	·0		9	0

The ore bed is of a quality suitable for metallurgical purposes over a very large area, as may be judged from the fact that it has been wrought at each of the following places :—

Blisworth	Finedon	Northampton	Thrapston
Brixworth	Irchester	Ringstead	Towcester
Desborough	Kettering	Stamford	Wellingborough

To attempt a description of the ore bed, as seen at each of these places, would involve a considerable amount of repetition, so that only a few examples will be given, but they will be selected so as to illustrate, as fully as possible, the various conditions under which the bed occurs.

In the neighbourhood of Wellingborough, where perhaps the largest quantity of ore has been worked, it is found immediately under a superficial covering of sand, or sand and gravel, varying in thickness from 1 to about 4 or 5 feet. The thickness of the ore varies with the amount of denudation it has undergone in the different parts, sometimes reaching 10 feet and more. The ore is not worked down to the upper lias clay, one or two inferior beds being left on, but the clay is never far below the bottoms of the various pits. The unworked beds are of a concretionary character, but the cores are mostly of sand, the only iron they contain being in the surrounding rings. The ore, where thickest, is distinctly bedded, and of a concretionary character, consisting of softish yellow oolitic ore and thin irregularly shaped "shells" of hard brown ore. Some of the cores consist entirely of yellow sand, which, when closely examined, is seen to consist of grains of quartz, mostly below $\frac{1}{100}$ of an inch in diameter, coated with hydrated peroxide of iron. The proportion of brown and yellow ore here is about the same as at Lincoln.' Cores of

blue-green oolitic ore are scarce, and always occur near the bottom of the bed. In some parts of the ore "walls" of clay or sandy clay are met with. They extend from the top of the bed downwards, and appear to be filled joints, like the "gulls" in the ore at Cottesmore.

Where the ore is thin, and the cover perhaps also thin, so that weathering action has been favoured, there is frequently very little else but the brown ore "shells," which lie together in a very confused manner. The yellow ore originally forming the cores has probably been washed away, unless it be that the whole of it has been converted into brown ore by longer exposure. One fact may be noticed which is of wide occurrence in Northamptonshire, and that is, that the bed-planes, where the ore has been much altered, have a more rapid dip than the bed itself.

On the west side of the road leading from Wellingborough to Finedon, and not far from the latter place, the ore occurs under similar conditions to that of Wellingborough, but is thicker, being about 13 feet 6 inches under a sandy cover, varying from 1 to 4 feet. The upper three feet of ore is concretionary, cellular and fragmentary, as at Wellingborough, but the lower 10 feet is much more compact, and shows one very well defined bed-plane about the middle. This lower part of the bed is also intersected by two sets of vertical joints, many of which are wide, in some cases being more than an inch across, and they are mostly unfilled. Kernels of bluish and greenish carbonate are much more abundant here than at Wellingborough, and they are much commoner in the compact ore than in the fragmentary ore at the top.

The open vertical joints just referred to are a very conspicuous feature of the bed at Duston, near Northampton. Some of the joints there are as much as a foot wide. Sometimes they are filled with fine ore that has fallen from the upper part of the bed, in other cases they are open. The plane face exhibited by these joints, when viewed sidewise, does not show the slightest evidence of the concretionary condition of the ore, which is presented when the joints are viewed endwise. At

Duston, also, may be seen a striking instance of the fact already mentioned, that in some instances the bed planes dip at a greater angle than the bed itself. It is in that locality, too, that the ore bed attains its maximum development, having been over thirty feet thick in places.

On the opposite side of the road from the pit, near Finedon, already in part described, the ore passes in below the clay of the upper Estuarine Series, and has been worked in that position with a cover of 15 feet. Here the ore is still more compact, and more distinctly bedded than in the pit on the other side of the road, where there is only a porous drift covering, and it contains a larger proportion of green and grey kernels. These kernels are also of an increased size, some of them being as much as 18 inches in diameter.

On Hunsbury Hill, near Northampton, the ore is worked with a covering as thick as at Finedon, but there it is mostly of white sand belonging to the Northampton sand. With this amount of cover the ore is very compact, and is as distinctly bedded and jointed as any sandstone or limestone; but as it is followed down the hillside, where the cover becomes thinner and eventually disappears, there is a gradual approximation to the rubbly character presented by the bed in similar situations elsewhere.

The Northampton ore generally contains numerous organic remains, about two hundred and thirty-eight different species having been found by Mr. S. Sharpe, a list of the Cephalopeda, and of the commoner Lamellibranchiata being given below:—

Ammonites bifrons, *Phil.*
  „ insignis, junior, *Schubler.*
  „ Murchisonæ, *Sow.*
  „ Martinsii, *D'Orb.*
  „ opalinus, *Reni.*
Nautilus obesus, *Sow.*
  „ polygonalis, *Sow.*
  „ sinuatus, *Sow.*

Belemnites acutus, *Miller*.
„ Bessinus, *D'Orb.*
„ elongatus, *Miller*.
„ (phragmocones).
Cardium cognatum, *Phil.*
Isocardia cordata, *Buckm.*
Ceromya Bajociana, *D'Orb.*
Lima, various species.
Cucullæa, various species.
Macrodon hirsonensis, *Mor.* and *Lyc.*
Trigonia, various species.
Pecten demissus, *Phil.*
„ lens, *Sow.*

Most of the shells of these organisms have had their limy matter replaced by peroxide or carbonate of iron, and adjoining the shells there is frequently a narrow band of the brown denser ore.

The composition of the ore in different parts of the district is set forth in the following table :—

Constituents.	1 Stamford brown ore.	2 Stamford grey ore.	3 Towcester.	4 Wellingborough.	5 Thrapston.
Water at 212° Fahr. ...	4·12	—			
„ combined and organic matter ...	7·76	—	14·60	11·37	14·16
Peroxide of iron ...	57·55	—	64·62	52·20	64·72
Protoxide of iron ...	—	29·89	—	—	—
Oxides of alumina and manganese	4·07	2·11	3·91	7·64	3·49
Lime	3·62	10·96	·90	7·13	3·96
Magnesia	·50	2·44	·25	·57	·53
Carbonic acid	2·82	30·37	—	4·92	—
Phosphoric „	·76	·79	2·15	1·26	2·06
Sulphuric „	·02	trace	·05	—	·07
Soluble silica	—	·12	—	1·60	—
Insoluble silicious matter	18·78	23·32	13·52	13·55	11·40
Total	100·00	100·00	100·00	100·24	100·39
Metallic iron	40·28	23·25	45·24	37·00	45·30

These analyses are given merely as illustrations of the different classes of ore, and not to show the general composition of the ore yielded by the particular districts named. The lime, it will be noticed, is very variable, in some cases being almost absent. There is also considerable variation in the alumina. Silica is the predominant non-metallic mineral. The above analyses being of specimens in an air-dried condition, give a higher percentage of metallic iron than the ore contains *in situ*. Moreover, 3 and 5 are better than average samples, for, taken as a whole, this ore, as it comes from the bed, will not yield more than about 34 or 35 per cent. of metallic iron. This is less than is given in most published analyses, and for the reason that they do not, as a rule, take into account the full quantity of moisture. This remark also applies to the bulk of the published analyses of other ores of this class.

The average of 18 analyses gives the percentage weights of lime, etc., in the ore as follows :—

	Average.	Variations.
Silica	11·59 ...	2·16—29·07
Alumina	5·76 ...	1·56—15·13
Lime	2·40 ...	·0—25·68
Magnesia	·62 ...	·0— 4·13

The average specific gravity of the ore may probably be taken at 2·5, and its porosity varies from about 13 to 30 per cent.

Deposits in the Middle Oolite.

Wiltshire. The only deposit at present working in these rocks is a bed at Westbury station, in Wiltshire, but, some years ago, the same bed was wrought near Heywood, a few miles north of Westbury. It occurs in the upper part of the coralline rocks, as shown in Plate II. At Abbotsbury, in Dorsetshire, there is a similar deposit on the same horizon, but it is not worked, so that the following remarks will be confined to the former locality.

The rocks occurring here are as under:—

	Ft.	in.	
Blue (Kimmeridge) clay (roof).			
Ironstone	11	6	
Greenish sand	4	0	
Oolitic limestone	28	0	
Stiff marl	12	0	
Sand, with four or five beds of rock, about 1 foot thick ...	50	0	(lower calcareous grit).
Oxford clay.			

The dip of the ore bed is to the east, at about 1 in 14 to 1 in 20. Its thickness, just under the Kimmeridge clay, including inferior bands, is about 11 ft. 6 in., but it appears to grow thinner to the dip, for about 400 yards eastward from the present working face, a sinking was made through 50 feet of Kimmeridge clay, and the ore was found to be only 2 feet thick. On the opposite side of the railway from the present workings, that is to the rise, the thickness was about 14 feet.

Where the overlying rocks are thin or porous the ore is a brown hydrated peroxide, but under the Kimmeridge clay it is a dark bluish or greenish carbonate, the change from one class of ore to the other being gradual, and dependent, in part, upon the thickness of the cover.

The ore is thin-bedded, particularly near the top, and where blue is fairly compact, and works off in flakes as at Frodingham and Caythorpe, but the brown ore is in a very loose and fragmentary condition. Nine inches of the bed just under the Kimmeridge clay is shaly and fossiliferous, and is consequently rejected in working. Below this there is a 2 ft. bed of good ore, and then another fossiliferous band 9 inches thick, which is also thrown away. The remainder of the bed below, 8 feet thick, is all sent to the furnaces.

The composition of the two kinds of ore is given in the following analyses, though the quality of the samples from which the results were obtained was better than the average.

	Dried at 212° Fahr. Brown ore.	Dark greenish ore.
Water (combined)	13·70	—
Peroxide of iron	59·93	1·32
Protoxide „	—	47·25
Silica	18·99	14·72
Alumina	3·22	5·46
Lime	1·84	·74
Magnesia	·84	·36
Phosphoric acid	—	trace
Sulphuric „	—	·10
Carbonic „	1·45	30·01
Total	99·97	99·96
Metallic iron	41·95	37·67
„ „ in the raw ore, about	37·00	35·00

The dark bluish or greenish ore effervesces when wetted with acid, but the brown does not. The average specific gravity of the brown ore is about 2·5, of the blue and green ore, 2·6, and their respective porosities are about 25 and 14 per cent.

The ore, both blue and brown, is very oolitic, and the grains are mostly hollow. Organic remains are not abundant, except in the two inferior bands, which are rejected in working. In them *Ostrea deltoidea* occurs in large numbers. A list of the fossils found throughout the bed is given below, after Hudleston and Blake.[1]

Ammonites Berryeri, Les.
„ decipiens, Sow.
„ pseudo-cordatus, Bl. & H.
Cordium delibatum, De Lor.
Pholadomya hemicardia, Ag.
Perna quadrata, Sow.
Pecten lens, Sow.
„ nudus, D'Orb.
„ distriatus, Leym.
Ostrea deltoidea, Sow.
Serpula.

[1] "On the Coralline Rocks of England," *Quarterly Journal of the Geological Society*, vol. xxxiii., 1877.

Deposits in the Lower Cretaceous Rocks.

Iron ore has, in recent times, been worked at two places only in these rocks, viz., in North Lincolnshire and Wiltshire, but formerly this horizon was one of the principal sources of this mineral in the country. In the old days, when charcoal was the fuel used in iron smelting, the counties of Surrey and Kent were famous for their iron furnaces, and the ore smelted in them was obtained from the cretaceous rocks of the Weald; but the scarcity of timber, combined with the introduction of coke elsewhere, put a stop to these once important industries.

Claxby, Lincolnshire. Along the rising ground, which occurs on the west of the Lincolnshire Wolds, there crops out a group of strata belonging to the Neocomians. From palæontological considerations they have been divided into lower, middle, and upper. In the middle group there is a bed of iron ore, which has been worked in a small way at Hundon, near Caistor, and about seven miles further south at Tealby. It is, however, only near Claxby that any quantity of ore has been obtained. The bed there comes to the surface about halfway up the steeply rising ground, which extends southwards from Acre House by the eastern side of the village of Claxby, and it is worked by means of mines, which, at the present time, have extended about half a mile into the hill. The geological position of the ore bed is shown in the section below, which was obtained in sinking an air shaft to the mine.

			Ft.	in.
		Soil	2	6
		White chalk	10	0
		Yellowish clay and red marly chalk ...	10	0
Neocomian.	Upper	Red sand	10	0
	Middle	Limestone	14	0
		Blue clay	40	0
		Yellow clay	2	0
		Iron Ore	6	0
		Clay	6	0
	Lower	Coarse greenish white sand	6	6

The dip of the bed is to the east, at a very low angle, and the thickness of the workable part of it is about 6 feet. Under

it there are from 5 to 7 feet of hard yellowish clay; below this again is coarse greenish sand, in which are blocks of sandstone formed of the same kind of sand as that above, but set in a limy matrix. The roof of the ore is clay for about 2 feet, above that is clay with iron ore.

The ore is a brownish-yellow hydrated peroxide, very oolitic, the grains being mostly of a shining black and hollow. It has this prevailing brownish-yellow colour, even where the working faces are at present half a mile in from day. It is, however, much harder now than it was at the outcrop.

Organic remains are numerous, the most common form being *pecten cinctus*. The various species found in the ore are named in the following list, after Keeping[1]:—

Belemnites lateralis, Phil.
　　„ quadratus, Röm.
　　„ sp.
Ammonites noricus, Schl.
　　„ plicomphalus, Sow.
Exogyra sinuata, Sow.
E. Tombeckiana, D'Orb.
Pecten cinctus, Sow.
　　„ striato-punctatus, Röm.
　　„ sp.
Avicula macroptera, Röm.
Lima Tombeckiana, D'Orb.
　　„ sp.
Pleurotomaria neocomiensis, D'Orb.
　　„ sp.
Species of Trochus, Turbo, Neritopsis, and Emarginula.
Pilcopsis neocomiensis, Gardu.
Ostrea frons, Park.
Trigonia ingens, Lyc.
Astarte robusta, Lyc.

[1] "On some Sections of Lincolnshire Neocomian," *Quarterly Journal of the Geological Society*, vol. xxxviii., 1882.

Species of Modiola, Cucullæa, Tellina, Sphæra, Cyprina, Myacites, Pholadomya and Sowerbya.
Serpula lophioides, Goldf.
„ gordialis, Schl.

The constituents of the ore have been determined by analysis to be as follows :—

Water at 212° Fahr.	5·68
„ combined	10·48
Peroxide of iron	52·86
Oxides of alumina and manganese	6·45
Lime	2·00
Magnesia	1·57
Phosphoric acid	·24
Sulphuric „	trace
Carbonic „	2·94
Insoluble silicious matter	17·26
Total	99·48
Metallic iron	37·00

The sample giving these results was in a highly air-dried condition, so that the metallic iron is from 3 to 4 per cent. higher than would have been obtained from the same piece of ore immediately after it came from the mine. For the same reason the water given off at 212° Fahr. is less.

The average specific gravity of the ore is about 2·5, and its porosity about 25 per cent.

In Hunt's ' British Mining " the Claxby bed is stated to be in the lower Lias. This is not correct.

Seend, Wilts. Some years ago, when the furnaces at Seend were working, a considerable quantity of ore was obtained between where they stand and the village. It occurs in the lower greensand, which there reposes on the Kimmeridge clay, as shown in the East Somerset and West Wilts section, Plate II. Scattered through the sand, and parallel to the false-bedding, are irregular lines of orey concretions, in which the bulk of the iron that occurs in the deposit is concentrated. Many of the concretions have a core of yellow sand, the grains

of which are from $\frac{1}{10}$ to $\frac{1}{80}$ of an inch diameter, and consist of silica dusted with hydrated peroxide of iron. When exposed to the wind, this sand is in many cases blown out, so that a face which has not been worked for some time has a very cellular appearance. Between the different bands of irony concretions the bed consists mostly of sand, of a similar character to that just mentioned, which is in places thickly set with silicious pebbles, some as much as three-quarters of an inch on their larger axis. The bed is much softer in these sandy parts than where it is richest in iron. Occasionally the deposit is traversed by strong vertical joints, some as much as a foot wide, and open. Others are filled with surface material. In this respect the deposit, when seen from a little distance, bears a striking resemblance to some of the ore in Northamptonshire.

As a rule, the deposit is not worked down to the Kimmeridge clay, about 6 feet at the bottom being so pebbly, and otherwise poor, that it is usually left. The greatest thickness that has been worked is about 28 feet, but ordinarily it will run about 18 to 20 feet, with a cover of from 4 to 5 feet.

The quality of the ore, as despatched to the market, although certainly silicious, is not so bad in that respect as might be expected. This is owing to the fact that most of the sand and pebbles are easily separated in working. Below, are the results of an analysis of a piece from the orey part of the deposit:—

Peroxide of iron	64·61
Silica	18·02
Alumina	3·85
Lime	·64
Magnesia	·20
Phosphoric acid	·64
Water	11·85
Total	99·81
Metallic iron	45·22

The average specific gravity of the orey part of the bed is about 2·5, and its porosity varies from 13 to 22 per cent.

III. General Observations.

In taking a general view of the deposits, one or two rather important facts appear. In the first place, it will be observed, they are all in close association with immense masses of clay. Taking the Seend ore first, it is seen that, although that deposit occurs in the lower greensand, yet it rests directly on the Kimmeridge clay. Proceeding next to the Claxby ore, in the middle Neocomian, it is found to be practically based on the same clay, there being only about six feet of coarse sand intervening. Then, the Westbury bed, on the coralline rocks, is at the base of the Kimmeridge clay. Coming to a still lower horizon, the deposits of the inferior oolites of Yorkshire, Mid-Lincolnshire, Rutlandshire, and Northamptonshire are all found at the top of the enormous mass of clay which constitutes the upper lias, whilst, at the base of that clay, there are the extensive beds of ore that are worked in Cleveland, Lincolnshire, Leicestershire, and Oxfordshire. Lastly, the Frodingham ore occurs in the midst of a great body of clay.

Another fact, which is probably more than an accidental occurrence, is that the deposits, for example, at the top and bottom of the upper lias—that is to say, the ores of the inferior oolite and the Marlstone rock-bed—do not, so far as is known, attain their maximum development in superposition, but alternately; thus, in Cleveland, when the "main seam" (of the middle lias) is best, there is scarcely a trace of the "top seam" of the inferior oolite; whilst, in Rosedale, where the latter seam acquires its greatest importance, the former seam has almost disappeared. Again, the ore of the inferior oolite extends in a more or less workable condition, from Lincolnshire southward to Coleby, whence it rapidly deteriorates, but at Caythorpe, a few miles south of Coleby, the Marlstone rock-bed is highly ferruginous, and continues so, in a greater or less degree, to Holwell, in Leicestershire, but to the south of that place, through Rutlandshire and Northamptonshire, it has more of the character of a limestone than of an

iron ore. Simultaneously with the deterioration of this bed, south of Holwell, there is a marked improvement in the ore-bearing zone of the inferior oolite. At Cottesmore, in Rutlandshire, it is so well developed as to be workable, and it preserves that condition, more or less, through Rutlandshire and Northamptonshire, as far as Towcester, where it dies out. A few miles beyond, at Adderbury and King's Sutton, the Marlstone rock-bed again becomes a workable ore, and continues so to Fawler, the most southerly point at which ore has been obtained from either of the two horizons under consideration.

The number of places at which the deposits immediately above and below the Kimmeridge clay have been worked is too small to enable it to be determined whether a similar alternation exists in them, but it would seem as if it did, from the relative position of the deposits at Westbury and Seend. The writer does not wish to attach an undue importance to this alternation of deposits in different horizons, as further explorations may prove that it is more apparent than real, but he considers the facts, so far as known, to be at least worthy of mention.

When the deposits on any given horizon are examined over a large area, it is found that there is not a great difference in their chemical constitution. Besides the hydrated peroxide or carbonate of iron contained in these ores, they all possess a considerable proportion of ordinary rock-forming minerals, such as silica, alumina, lime, and magnesia. The relative percentage weights of each of these different materials in the ores of the inferior oolites and middle lias, at most of the places where they have been worked, are given in the following statement:—

ORES OF THE INFERIOR OOLITE.

	Silica.	Alumina.	Lime.	Magnesia.	Totals.
1. Rosedale ...	13·33	8·34	5·09	2·75	29·51
2. Mid-Lincolnshire	13·67	4·59	3·24	·36	21·86
3. Rutlandshire ...	11·91	8·05	·50	·45	20·91
4. Northamptonshire	11·59	5·76	2·40	·62	20·37

ORES OF THE MIDDLE LIAS.

	Silica.	Alumina.	Lime.	Magnesia.	Totals.
5. Cleveland ...	11·42	8·63	5·13	2·99	28·17
6. Caythorpe ...	11·14	9·09	7·12	·52	27·87
7. Holwell	11·40	9·02	3·60	1·06	25·08
8. Fawler	11·21	7·14	8·35	·66	27·36

Nos. 2, 4 and 5 are each the average of eighteen promiscuous analyses. The others are of fairly average samples.

The ores on both horizons, it will be noticed, contain more magnesia in Yorkshire than anywhere else. The silicious and aluminous materials are together fairly constant throughout. The greatest variation is in the lime. 1 and 5 are carbonates, the others are hydrated peroxides. The former contain a larger proportion of these rock-forming materials than the latter, but they hold much less water.

CHAPTER VIII.

THE IRON ORES OF ANTRIM.

LITERATURE.

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3. *Memoir of the Geological Survey*, 1876. Explanatory Memoir to accompany sheets 21, 28, and 29, by Edward Hull.
4. "The Iron Ores of Antrim," by J. D. Kendall. *Colliery Guardian*, Oct. 27th, 1876.
5. "On the Tertiary Iron Ore Measures, Glenariff Valley, County Antrim," by Phillip Argall. *Proceedings of the Royal Dublin Society*, vol. iii., 1881.
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STRATIGRAPHICAL AND LITHOLOGICAL PARTICULARS.

COUNTY ANTRIM is almost entirely covered by a sheet of basalt, which varies in thickness according to the amount of denudation it has undergone, from a few feet to about 1,000

feet. This basalt rests upon "white limestone," the equivalent of the upper chalk, and appears, from the nature of the plants yielded by some inter-bedded layers of lignite, to be of Lower Miocene age.

The basalt may be divided into three classes, amorphous, columnar, and concretionary, all of which can be seen by those who visit the famous Giant's Causeway, on the north coast. Like other volcanic rocks of a similar character the basalt is distinctly bedded, as in the cliffs at Pleaskin, near the Giant's Causeway.

Over a large part of its area it has a low dip to the south, but in some of the small outliers the dip is in other directions and at higher angles. The basalt is usually divided into upper and lower, the former having a maximum thickness of about 400 feet and the latter of about 600 feet. They are separated by the iron-ore beds presently to be described, which form a convenient line of division, as they are so easily recognised.

Parallel to these ore beds, and inter-stratified with both the upper and lower basalt, are a number of other ferruginous bands. The precise number is not known, but they occur one above another like seams of coal, as in the cliffs near Downhill. There, only two are to be seen, but in other places there are more. In Cape Pleaskin five of these bands can be seen in the lower basalt. Usually they consist of a ferruginous clay called "bole," with an underlying layer of lithomarge. Below are two analyses of the basalt:—

	No. 1.	No. 2.
Peroxide of iron	27·87	8·95
Silica	39·72	53·70
Alumina	14·32	25·41
Lime	4·15	4·55
Magnesia	4·00	—
Soda ... ... } Potash ... ... }	9·94	—
Sulphuret of iron	—	trace
Water	—	4·30
Total	100·00	

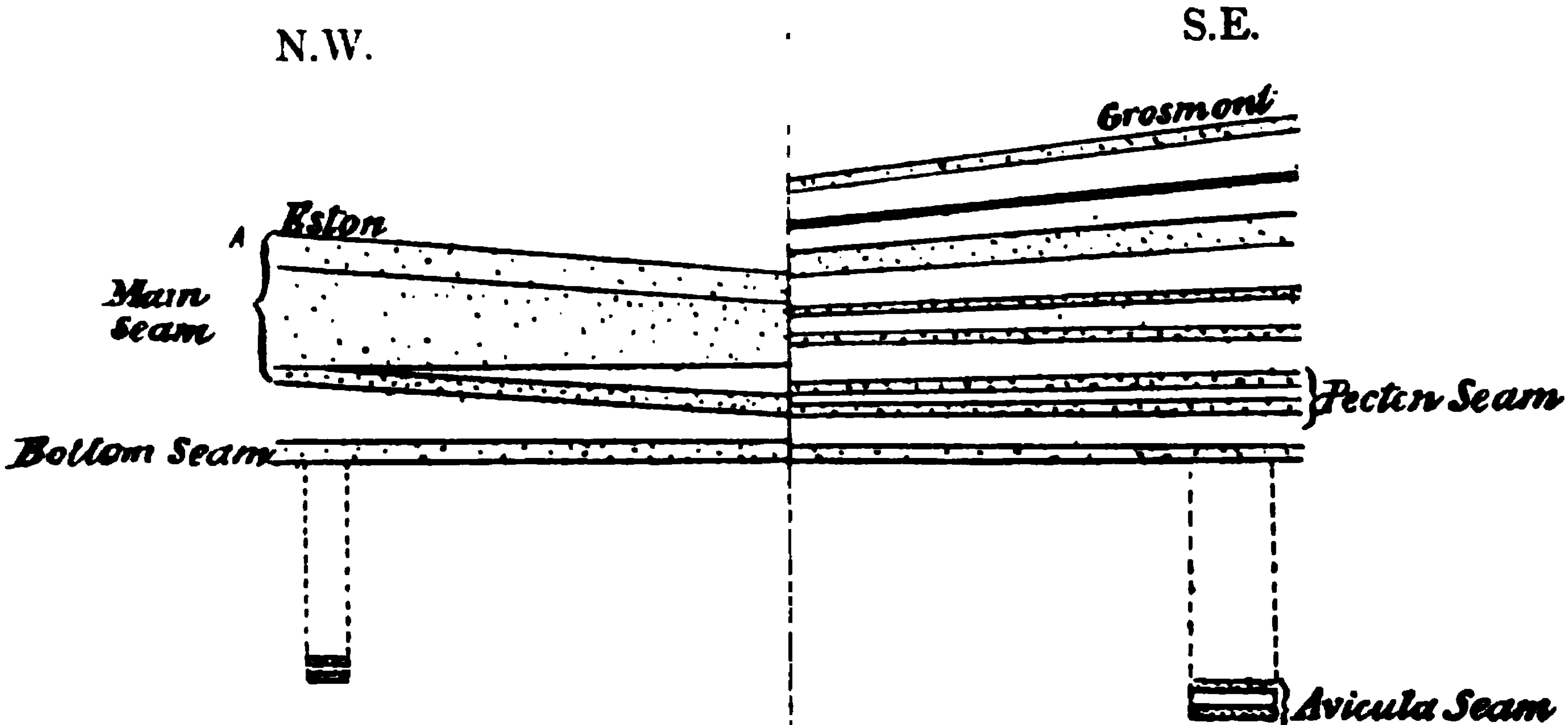

PLATE IV.—DIAGRAMMATIC SEAM IS SPLIT TOWARDS THE S.E.

Position of Ores and their Nature.

The position of the ores between the upper and lower basalts is well seen at Portmoon, on the north coast, where they occur in beds immediately under the lower tier of basaltic columns.

The seams, which occur in a similar position in the cliffs near the Giant's Causeway, are the same. They have been worked by " day " levels in various parts of the county, as at Urblereagh and Ballylagan, near Portrush, Duneany, near Glarryford, at Lyle Hill and Ballypallidy, near Templepatrick, Glenariff, near Red Bay, Kilwaughter, and Glenarm, and on Island Magee; but the most important operations have been carried out along the line of the Ballymena and Cushendall Railway. These openings have been made into the hillsides along the outcrop, at Newton Crommelin, Evishacrow, Parkmore, Glenravel, Cargan, Dungonnel, Mount Cashel, Rathkenny, Elginny, Knockboy, Coreen, Ballylig, and Clonetrace. A general section of the seams is given below.

Roof.—**Upper basalt.** Sometimes Columnar.

Clay (called by the miners "brushing"). Slate coloured passing gradually into the overlying basalt. The thickness of the clay is very irregular, varying from an inch to 2½ feet, with an average of about a foot. It peels off the overlying basalt in laminæ, parallel to the sinuosities of the under surface thereof.

Pisolitic Ore, locally called "shot" ore, consists of a soft, brown or reddish aluminous poor ore, in which are thickly imbedded small, and approximately spheroidal, pieces of rich, hard ore, often black, and generally about the size of peas or less, but sometimes as large as walnuts, the larger being near the top. Some of them are strongly attracted by the magnet. The junction between this bed and the overlying clay is very distinct, and the two separate quite easily. This ore is the most important in Antrim for the purposes of iron-

making, and on that account is, at present, mainly worked. Its thickness varies from 3 or 4 inches to nearly 4 feet.

Bole, called by the Miners "pavement." A reddish or brownish ferruginous rock containing numerous concretionary nodules of basalt. Sometimes the iron is distributed in irregular layers or nodules, the remainder of the bed having the character of bauxite. It is moderately hard, and breaks into irregular cuboidal pieces. The junction between this and the overlying pisolitic ore is not very distinct. It varies in thickness from 8 to 17 feet.

Lithomarge, locally called "marge," is a variegated soft rock of a prevailing blue-slate colour and greasy feel. Like the bole, it contains concretionary nodules of basalt, but they are more numerous in this bed than in the bole. The line separating it from bole is somewhat indistinct. Its thickness ranges from 12 to 60 feet.

Sole :—**Lower basalt** :—Concretionary, passes gradually into the overlying lithomarge.

A section of the three beds, as seen at the outcrop at Urblereagh, near Portrush, is shown in Fig. 23.

Pisolitic Ore. The thickness of the pisolitic ore varies sometimes very abruptly. Where it is very thin, or has disappeared altogether, it is said to have had a "squeeze."

Particulars of the thickness at various places are given below :—

	Thickness of Pisolitic Ore.							
	In.		Ft.	in.		Ft.	in.	
Parkmore	4	to	2	0	average	1	0	
Mount Cashel	4	„	3	10	„	1	3	
Newton Crommelin ...	6	„	3	6	„	2	0	(nearly).
Ballylig	4	„	2	0	„	1	2	
Duneany	6	„	1	6	„	1	0	
Lyle Hill	6	„	1	6	„	1	0	
Glenariff	6	„	2	6	„	1	6	
Cargan	6	„	2	0	„	1	6	

Sometimes the bed is absent over large areas. In other parts it is indurated by intrusive dykes. In certain areas it has an amorphous character, no pea-like bodies in it at all, as at Urblereagh, near Portrush. There, a quantity of fossil wood, belonging to a species allied to the yew, has been found, the vegetable tissue being replaced by limonite. The bed everywhere contains fewer nodules than usual. At Ballipallidy, plant remains of the genera *Pinus*, *Sequoia*, *Cupressites*, *Plantanus*, etc., have been found in the thin clayey bands associated with the ore.

The dip of the beds is, like that of the basalt, generally to the south at low angles. At Parkmore, for example, the dip

FIG. 23.—SECTION AT URBLEREAGH.

References—*A* Upper Basalt. *B* Clay, 1 Ft. *C* Pisolitic Ore, 1 Ft. 9 In. *D* Bole, 7 Ft. *E* Lithomarge. *F* Lower Basalt.

is south, from 1 in 30 to 1 in 60. At Mount Cashel it is in the same direction, at about 1 in 24.

The extent of the pisolitic ore and its accompanying bole and lithomarge is not accurately known, but they may be taken to cover about 800 square miles, although they do not occur everywhere within the basaltic area, in many places having been removed by denudation, being found in the hills but absent in the intervening valleys. The breach of continuity thus brought about is further increased by faults and dykes traversing the basalt. Some of these will doubtless prevent much of the ore from being worked.

The quality of the pisolitic ore is good, although it varies much in different parts of the district, the aluminous matrix

being more abundant in some parts than others. As sent to the market it will yield from 36 to 45 per cent. of metallic iron. Its composition is shown by the following analyses:—

Constituents.	Glenariff.	Glenariff.	Cargan.	Broughshane.	Knockboy.
Peroxide of iron ...	62·43	71·64	66·56	65·42	63·70
Protoxide " " ...	4·75	1·88	—	—	—
" " manganese	·28	·27	·11	trace	—
Silica	8·40	5·05	5·47	7·08	6·30
Alumina	10·19	4·25	7·92	12·54	12·75
Lime	2·80	·81	·68	·20	·10
Magnesia	·59	·61	·16	·08	·05
Phosphoric acid ...	—	·20	trace	·02	·06
Sulphur	—	—	·03	trace	·02
Titanic acid	—	8·89	3·68	5·28	4·60
Water	1·88	—	14·34	8·82	12·70
" hygroscopic ...	8·48	6·40	—	—	—
Total	99·80	100·00	98·95	99·44	100·28
Metallic iron	47·40	51·58	46·61	45·99	44·60

The specific gravity of the pisolitic ore varies from 3·34 to 3·45 taken generally, but there are some parts of it, in which the pea-like bodies are more numerous and apparently fused together, which have a specific gravity of 3·58. The nodules alone average about 3·9. The moisture in the bed ranges from 3·7 to 4·7 per cent.

It has several times been contemplated to crush the ore and wash it, so as to free the nodules from the poorer matrix, and thereby increase the metallic yield. In fact, one or two companies have attempted it; the object being to put the ore into the market solely for its iron, and not simply as a flux, for which it has hitherto been mainly used. With the hæmatites of Cumberland and Lancashire about 10 per cent. of the pisolitic ore is used for fluxing purposes alone.

Bole yields much less iron than the pisolitic ore, ranging from 20 to 25 per cent., but contains a larger quantity of alumina. The ratio of the alumina to the silica is also higher

than in the pisolitic ore. This makes it valuable as a flux for the silicious ores of Cumberland and Lancashire, and will no doubt always keep down the price of the pisolitic ore, which is used by preference only, because the unit price of the iron compares favourably with that of hæmatite. The demand for bole at present (1890) is, however, not large, on account of the relatively low price of pisolitic ore; the consequence is that a large quantity of the bole, worked to make height in the "horse" or "hutch" roads, has to be stowed away in the old workings.

The following are analyses of samples taken chiefly from the bole, but having a larger or smaller admixture of the pisolitic ore:—

Constituents.	Lyle Hill.	Glenariff.	Glenarm.	Tully.
	Dried at 212° Fahr.			
Peroxide of iron	46·40	35·93	33·34	45·50
Oxide of manganese	·06	·11	—	trace
Silica	5·62	12·20	3·78	4·00
Alumina	27·44	36·50	41·13	35·50
Lime	·50	0·53	·21	·35
Magnesia	trace	1·41	·97	—
Phosphoric acid	·03	—	·04	—
Sulphuric acid	·07	—	trace	—
Titanic acid	1·55	—	5·31	2·00
Water of combination	18·62	10·23	15·55	12·65
Total	100·29	96·91	100·33	99·90
Metallic iron	[1] 32·40	25·15	23·34	31·85

Lithomarge. The yield of iron by lithomarge is too small to render it of any value in ironmaking except as a flux. It has, however, been used frequently in that way, although it is not so valuable as bole, because the percentages of alumina

[1] The raw ore contains 29·23 per cent. of metallic iron and 10 per cent. of moisture. Taking this bed generally, the moisture varies from 10 to 17 per cent., and the specific gravity from 2·6 to 2·87.

and silica are more nearly equal in lithomarge than in bole. Its composition is shown by the following analyses :—

	No. 1.		No. 2.
Peroxide of iron	6·61	...	25·05
Silica	49·75	...	30·70
Alumina	29·88	...	27·05
Lime	·43	...	1·11
Magnesia	1·47		
Potash	6·35	...	—
Water	5·48	...	15·85
Total	99·97	...	99·76
Metallic iron	4·62	...	17·53

The nodules of basalt included in the bole and lithomarge are very curious. The centre of the nodules consists of compact basalt, which gradually and by concretionary layers passes into either bole or lithomarge.

CHAPTER IX.

SOME OF THE IRON ORES OF SPAIN.

Introduction.

SPAIN cannot be called an iron-making country, nevertheless it contains enormous quantities of excellent iron ore of various kinds. These, although not much used at home, have for the last twenty years been exported in increasing quantities to different quarters of the globe. Some iron and steel are made at Bilbao and in the Asturias, but very little compared with that produced in other countries from the exported ores of Spain.

For obvious reasons the ores hitherto worked occur within a few miles of the sea. On the north coast, along the Cantabrian range of mountains, iron ore has been worked more or less extensively in the provinces of Navarra, Guipuzcoa, Vizcaya, Santander, and Oviedo. Along the southern coast it has mainly been obtained from the provinces of Sevilla, Malaga, Almeria, and Murcia. Small quantities have also been produced by some of the interior provinces, such as Ciudad Real and Badajoz, but these ores have not as yet attained any commercial importance.

The deposits which it is intended more particularly to describe are those occurring in the provinces of Vizcaya and Santander, in the north, and in the province of Malaga, in the south. In these are found all the various descriptions of ore used in the manufacture of Bessemer iron, such as siderite, limonite, hæmatite, and magnetite, and they are all of excellent quality.

The commercial importance of the Vizcayan ores will be gathered from the following table of output, mainly from that province, but partly from that of Santander, between 1861 and 1890.

Year.	Tons.
1861	54,000
1862	69,000
1863	70,000
1864	118,500
1865	100,700
1866	90,500
1867	134,000
1868	152,000
1869	162,000
1870	246,400
1871	268,500
1872	423,000
1873	386,000 [1]
1874	47,700
1875	32,350
1876	390,000 [2]
1877	862,000
1878	1,224,730
1879	1,117,836
1880	2,345,000
1881	2,500,532
1882	3,855,000
1883	3,627,752
1884	3,216,321
1885	3,311,419
1886	3,185,228
1887	4,170,422
1888	3,591,637
1889	3,885,612
1890	4,272,918

For the last eight years the production has been equal to the combined yield of Furness and Cumberland, and the greatest part of it has come to the British Isles.

[1] Carlist war began in July.
[2] Carlist war ended in March

Provinces of Vizcaya and Santander (part of).

Literature.

The only papers that have come under the writer's notice dealing with the subject under consideration at any length in this area, are the following:—

1. "Criaderos de hierro de Somorrostro," by Ramon Adan de Yarza. Published 1876 in the *Boletin de le Comision del Mapa Geologico de España.*
2. "On the Somorrostro Mines," by E. Bourson. *Revue Universelle*, vol. iv.
3. "On the Deposits of Iron Ore occurring in Spain," by G. Prus. *Le Génie Civil*, vol. v., p. 145.
4. "Criaderos de hierro de Vizcaya," by Ignacio Gœnaga. *Revista Minera y Metalúrgica*, Series C., vol. i., 1883.
5. "The Iron Ores of Spain," by J. D. Kendall. *Transactions of the Federated Institute of Mining Engineers*, vol. iii., 1891-92.

Physical Features.

These provinces are situate on the northern slopes of the Cantabrian Range along the shore of the Bay of Biscay. The ground is mostly hilly, or mountainous, there being very little flat or low-lying ground even along the seashore. The mountains are very regular in outline, and the foothills frequently cone-shaped, giving them the appearance of extinct volcanoes. The greatest altitude reached is 1,650 feet, but the highest point at which ore has been worked is about 1,150 feet. It occurs mainly at elevations ranging between 600 and 1,100 feet, but in smaller quantities, down almost to the sea level.

Geological Structure.

This, so far as relates to the question under discussion, is comparatively simple. Stratigraphically, the rocks are capable of division into three parts, as below, which are conformable to one another:—

1. Light grey shale, very calcareous.
2. Grey limestone.
3. Dark micaceous sandstone (calcareous).

The general dip of the strata is about north 45° east, but there are very great variations both in the direction and amount of dip. These have evidently been brought about by an upheaval of the Cantabrian chain in Tertiary times.

The thickness of these rocks, except the limestone, is not known, nor is it necessary to our purpose that it should be. The limestone, where undenuded and fully developed, may be taken at about 250 feet thick. All the three formations are fossiliferous, although it is frequently very difficult, and at times impossible, to ascertain their specific relations. This is especially so in the limestone. The organic remains found in the grey shale, overlying the limestone, include the following: *Turbo renaiescianus* and *Ostrea conica.* In the limestone there are species of *Ostrea*, *Requienia*, *Terebratula*, *Astræa*, and *Mandrina.* The dark sandstone, underlying the limestone, has yielded *Sphærulites foliaceus*, *Caprina Verneuilli*, *Ostrea carinata*, *Rhynchonella contorta*, *Cidaris vesiculosa*, *Pygaster truncatus*, and *Pseudodiadema granularis.*

The presence of these remains makes it clear that the rocks in which they occur belong to the Cenomanian division of the Cretaceous, somewhere near the position of the upper greensand of England.

The shales above the limestone are light grey in colour, of a nodular character, and contain a considerable amount of lime.

The sandstones, under the limestone, are a very dark grey (almost black when wet), micaceous, and much more compact than the shale.

The limestone is an ordinary grey, compact stone, not unlike in appearance to the carboniferous limestone of England.

Ore Deposits.

These occur exclusively in the limestone, and are therefore clearly limited in thickness or depth, at any particular point,

by the vertical extent of that rock. This most important fact, from an economic standpoint, does not even yet appear to be recognised, except by those who have had a geological training. The consequence is that it is not uncommon to hear the Bilbao deposits spoken of as "mountains of ore." This erroneous notion arises mainly from the fact that the sides of the mountains have, in places, the same dip as the limestone, or as the ore, where that has entirely taken the place of the limestone. Under such circumstances it is clear that the whole face of a mountain might show ore, and seem to the uninitiated to be a mountainous mass of mineral, whereas, in reality, it would simply be a crust of ore. Such occurrences are not uncommon. The writer has seen them in other parts of the world, as well as Spain, and they invariably suggest the same erroneous conclusions to those who have had no training in stratigraphy.

In some cases the originally enclosing limestone has been entirely removed from a deposit, by denudation, but the horizon can then be fixed by the dark sandstone which invariably occurs below the ore.

The largest deposit of ore occurs on the Triano mountain. It is about 2 miles long by about ⅝ of a mile wide, and has a maximum thickness of about 220 feet. Another large body is at Matamoros. This is about 1¼ mile long by ⅓ of a mile wide, and ranging from 1 to 238 feet in thickness. Both these ore-masses have an irregular elongated form, and their longer axes correspond practically with the strike of the strata, which bears about north 45° west and south 45° east. Except where interfered with by faults this parallelism of their longer axes to the strike of the accompanying rocks is a feature of most, if not of all, the deposits.

A number of smaller patches of ore occur in the neighbourhood of Bilbao, El Regato, and Galdames, as well as at Dicido and elsewhere in Santander.

The ores yielded by these deposits are chiefly limonite, but there is also a considerable quantity of hæmatite, and some siderite or spathic ore. The local names of these ores are as follows :—Siderite = *siderosa* or *carbonato de hierro* ; limonite

= *rubio*; hæmatite = *campanil* and *vena*. We also meet with such names as *vena acampanilada*, *vena rubiada*, or *rubio avenado*; which are intended to describe, and, in fact, do describe, the compound character of the ores to which they are applied.

Siderite or Siderosa. This ore is met with almost exclusively at or near the base of the limonite and hæmatite deposits, mostly as kernels or nuclei of those ores. It does not, however, always appear in this form. Sometimes it is seen in large masses, under rubio, in which decomposition has not yet begun to operate. Where the ore adjoins limestone there is a regular transition from one mineral to the other. The colour of the ore is white or grey. Its quality is shown by the subjoined analyses:—

	No. 1.	No. 2.
Ferrous oxide	—	50·18
Ferric "	—	5·31
Carbonate of iron	91·62	—
" of manganese	2·36	—
Manganous oxide	—	1·00
Silica	4·50	3·60
Magnesia	—	3·21
Carbonate of lime	1·60	—
Lime	—	·87
Sulphur	—	trace
Phosphorus	—	—
Water and carbonic acid	—	36·28
Total	100·08	100·45
Metallic iron	44·23	43·96

Specific gravity ... ... 3·6 to 3·7

As the more easily worked limonite and hæmatite become exhausted no doubt this ore will have to be attacked, but at present it is neglected.

Limonite or Rubio. This is the most abundant ore in the two provinces, and some of the finest mines—or quarries rather (for there are no mines proper in the Bilbao district)—are working it; among these may be mentioned the Orconera and

the Conchas quarries. The ore has mostly the cellular and concretionary character, so familiar to those who are acquainted with the Northamptonshire ores, although in places it is quite compact and bedded. This latter character mostly happens near the base of a deposit. The cells frequently contain a large amount of sand and clay—up to one-third (by volume) of the ore—especially near the surface; and this is mainly the reason of the higher percentage of silica which analyses of this ore frequently exhibit as compared with those of campanil or vena, for it is not possible to separate the extraneous silicious material, entirely, in the ordinary operations of working. The colour of the ore is yellow and brown. Its quality is shown by the following analyses, which are of samples dried at 212° Fahr.:—

Constituents.	Ocronera (cellular).	Concha (cellular).	Anita (cellular).	Josefa (compact).
Ferric oxide	79·96	78·29	78·52	80·30
Manganous oxide	·70	·74	·55	·92
Alumina	1·44	1·15	1·00	2.82
Lime	1·00	·50	·31	·72
Magnesia	·55	·02	—	·40
Silica	8·10	8·80	7·98	5·42
Sulphuric acid	·10	·05	·02	·24
Phosphoric "	·03	·02	·06	trace
Water (combined)	8·25	10·55	11·80	9·12
Total	100·13	100·12	100·24	99·94
Metallic iron	54·62	54·80	54·96	56·21

The specific gravity of the cellular ore is about 2·9, and of the compact ore 3·5. This difference arises from the more porous nature of the cellular ore.

Hæmatite, or Campanil and Vena.—Two kinds of hæmatite are found in these mines: (1) campanil, of a reddish colour, fairly compact, and presenting very frequently the characteristic fracture of siderite; and (2) vena, of a dark bluish purple, inclined to be powdery, and to fall away on exposure to the air. It is then known as *vena dulce*; when

harder it is spoken of as *vena dura*. Both companil and vena are very porous, and frequently contain a mechanical admixture of lime, which, on examination under the microscope, is seen to fill the minute cavities which exist in the ore. Their quality is indicated by the analyses below :—

Constituents.	Vena.		Campanil.	
Peroxide of iron	90·70	91·70	84·00	78·03
Oxide of manganese	1·30	·70	1·90	·86
Silica	1·05	1·20	3·20	5·91
Alumina	·15	—	—	·21
Lime	1·00	·50	4·60	3·61
Magnesia	·02	·10	—	1·65
Sulphur	·03	·07	—	trace
Phosphorus	—	·02	trace	trace
Water and carbonic acid ...	5·40	5·40	6·00	9·60
Total	99·65	99·69	99·70	99·87
Metallic iron	63·49	64·19	58·80	54·62

The apparent specific gravity of vena varies from 3·1 to 3·5, and of campanil from 3·38 to 4. Both, as already mentioned, are exceedingly porous, and they absorb a large amount of moisture; but vena is the more porous, and it is owing to that fact that its apparent specific gravity is less than that of campanil, although its metallic yield is greater.

Campanil is confined to a small area on the Triano mountain. Immediately outside this area is a mixture of campanil and vena, but the latter also occurs, more or less abundantly, in the Triano ore mass generally (which is about half rubio), as well as in most of the deposits of rubio in other parts of the district. Campanil may sometimes be seen forming nuclei in rubio. It contains innumerable loughs, up to 3 or 4 inches diameter, and occasionally as much as 12 or 24 inches. In some cases they are of an elongated form and parallel to the bedding. These loughs are, as a rule, lined with either crystals of calcite or siderite. Often the ore varies considerably in hardness, and in an irregular manner.

Forms of the Deposits.—To any one who has been accustomed to work among the hæmatites of Whitehaven and Furness these Vizcayan deposits appear exceedingly simple, for they are practically all on the same geological horizon, a circumstance which adds materially to a ready comprehension of them, whilst at the same time it reduces the risk of the adventurer to a minimum. Further, the deposits are mostly bed-like in form, notwithstanding the fact that, in some cases from the effects of faulting, they seem to be vein-like. For instance, the deposit worked by the Anita mine, near Dicido, in Santander, has quite the appearance of a vein when viewed in section. The length of the southern part of the deposit is about 1,200 feet, its breadth from 50 to 95 feet; and at the time of the writer's last visit it had been proved to a depth of 120 feet, so that it might easily be mistaken for a true vein by any one unfamiliar with the stratigraphy of the district.

The relation of the deposits to the underlying dark sandstone is very well seen at the Josefa mine, near Bilbao, when looking southward from the northern end of the tunnel on the railway between Bilbao and Durango. At the southern end of this tunnel an interesting section shows the limestone and ore (rubio) in juxtaposition.

The relation of the ore to the overlying shale is best seen on the Triano mountain, in the San Miguel and Begoña quarries. The ore (campanil), which attains a thickness of about 220 feet, is overlain by grey shales. It is only here, in fact, where the campanil occurs, that this covering up of the ore by solid rock can be seen; in every other part of the district the deposits appear with a denuded top, and are either exposed to "day" or simply covered by a thin surface accumulation of sand and gravel. Indeed, the shales do not cover the whole of the campanil even, but where they have been removed the upper part of the ore has been converted into rubio, unless it be covered by limestone, as in the Aurora mine. In the latter case, and also when the overlying shale is present, the ore has mostly the campanil character throughout. Viewed horizontally, the deposits are very irregular in outline, and, as already

pointed out, their longer axes correspond with the strike of the strata; but the irregularities in their form have been mainly determined by the two sets of vertical jointing in the limestone.

Inner Nature of Deposits. In the rubio deposits—that is, the ore that has been most altered by weathering—the original character has almost disappeared. Some contain only a few nodules of siderite near the base, others none, but there are deposits that contain a large quantity of this ore in the lower parts.

A feature of the rubio deposits is the occurrence of numerous clay "backs" in the ore, similar to those met with in the ores of Northamptonshire and Rutlandshire. These clay "backs" occur in lines parallel to the vertical jointing in the limestone, and have doubtless been introduced, at a comparatively recent date, into vertical cavities in the ore, produced, by the shrinkage thereof, along certain divisional planes, during the alteration from siderite to limonite. The ore adjoining these masses of clay partakes largely of the character of vena.

In the campanil deposits we see many things to remind us strongly of the hæmatites of Whitehaven and Furness. First among these are the large irregular masses of limestone interbedded with the ore, as seen in the San Miguel mine or quarry. The same sort of thing could also be witnessed, some time ago, in the Begoña, Cæsar, Marquesa, Aurora, and other quarries in the same neighbourhood. A very interesting section of this nature was exposed, a few years ago, in the Cæsar mine. The dip of the interbedded limestone, as also of the partings in the ore, corresponded exactly with that of the limestone beds outside the ore mass.

Kernels of siderite occur in the campanil near the base, and here and there, at all levels, masses of brown silicious stone, which shade off gradually in all directions into the ore. Vena and rubio are also met with in campanil, but not in great quantity until we get into that part of the deposit which is uncovered by either limestone or shale.

So far as the writer is aware no organic remains have been found in the ore.

Province of Malaga (Part of).

Although this district has not attained the same importance commercially as that portion of Vizcaya and Santander which has been dealt with above, yet it is most interesting from a scientific point of view. It would no doubt soon be better known to the iron world than it is were it more opened up by railways, for there are some magnificent deposits of excellent ore that have not yet been touched, and that only need railways to render them available for immediate use.

Literature.

1. "The Deposit of Iron Ore at Marbella," by W. M. Vivian. *Transactions of the South Wales Institute of Engineers*, vol. xiv., pp. 48-52.
2. "The Iron Ores of Spain," by J. D. Kendall. *Transactions of the Federated Institute of Mining Engineers*, vol. iii., 1891-2.

Physical Features.

The area now to be considered forms part of the mountainous region known as the Serrania de Ronda, and extends from the shore of the Mediterranean Sea to an altitude of about 6,400 feet. Excepting a narrow slip along the sea coast the ground is entirely mountainous, and much of it quite bare of vegetation.

Geological Structure.

All the rocks met with in the area with which we are more particularly concerned belong to the Archæan age, and consist of dolomite, gneiss, amphibolite, mica-schist, and serpentine. As is usual with rocks of this class, the strata are much contorted, and frequently assume very high angles.

Ore Deposits.

The principal ore of iron found in this region is magnetic (*hierro magnetico*). Its quality is excellent, as will be seen on

reference to the following analyses of ore from three different parts of the area :—

	No. 1.	No. 2.	No. 3.
Peroxide of iron	68·04	70·40	59·43
Protoxide of iron	21·37	21·96	24·17
Oxide of manganese ...	1·40	trace	·22
Silica	2·60	0·30	7·13
Alumina	3·42	1·50	2·46
Lime	·20	trace	·44
Magnesia	1·18	3·36	5·41
Sulphur	·04	·04	·07
Phosphoric acid	·01	—	·02
Water and carbonic acid ...	1·74	2·44	·69
Total	100·00	100·00	100·04
Metallic iron	64·25	66·36	60·40

Its colour is black, and its specific gravity varies from 4·34 to 4·9. When pure the ore is quite opaque, as viewed under the microscope, but when somewhat mixed with country rock it has an entirely different appearance, being broken up in an irregular manner, by hornblende, etc.

Form of the Deposits.—These deposits of magnetite usually present the form of bedded veins, mostly with high angles, but sometimes their inclination is not very great. A deposit of this description occurs about four miles north-west of Estapona. The roof or hanging wall is dolomite, and the line of contact between the ore and roof-rock very irregular. The sole or lying wall is serpentine. When viewed in vertical section the deposit has exactly the appearance of the hæmatite deposits in the bottom limestone of the Whitehaven district—the roof being irregular in form, the sole quite regular. The deposit on this account varies greatly and suddenly in thickness and towards the rise disappears altogether, the dolomite resting on the serpentine. Where the ore and dolomite join, the two minerals are very intimately united, fine strings of ore running into the limestone, and *vice versâ*; whereas the junction between the magnetite and the serpentine below it is clear and distinct, and forms a regular line, such as we usually see at the junction of calcareous with silicious or aluminous beds.

The more usual mode in which this ore occurs is as highly inclined bedded-veins. A body of splendid ore having this form occurs at Robledal, about twelve miles due north of San Pedro el Cantara, at an altitude of about 4,500 feet. The deposit has a course about east and west, and hades to the south. The hanging wall is of serpentine, and the lying wall gneiss with dolomite. The vein can be traced for a considerable distance on the surface, but has not yet been sufficiently opened up to enable any one to say what may be its exact form, horizontally; but usually such deposits are found to be lenticular. This is perhaps the universal experience of deposits, in rocks of this age, in other parts of the world; and here, too, it is so, where they have been extensively opened out, as at Marbella, for instance; and although the extremity of the ore there in a south-westerly direction has not been reached, yet so much as has been proved is clearly of a lenticular form, notwithstanding the shiftings caused by cross-faulting. The direction of that deposit is north-east and south-west; the length already worked about 800 feet, its greatest breadth and depth 200 and 420 feet, respectively. The dip is in opposite directions at its northern and southern ends, the change taking place at a cross-fault about midway in its length. The hanging and foot walls of the deposit consist mainly of amphibolite and mica-schist, the latter, in places, showing beautiful large crystals of biotite. These rocks include, here and there, lenticular masses of dolomite. Similar masses of the same stone are occasionally met with between the ore and wall rock. The junction between the ore and dolomite is invariably very complicated, the two minerals frequently running into one another in threads, veins, and irregular masses, as is the case at the junctions of hæmatite and limestone in the deposits of West Cumberland and Furness.

Lenticular masses of amphibolite or other similar rock are frequently met with in the ore. Some little pyrite, chalcopyrite and also pyrrhotite are found in association with the magnetite, but not sufficient hitherto to interfere in any way with its commercial value.

PART III.

THE AGE AND ORIGIN OF THE DEPOSITS.

CHAPTER I.

AGE OF THE DEPOSITS.

IN approaching this subject we are struck by the curious fact that hæmatite does not exist in rocks younger than the Trias. It follows, therefore, that all hæmatite, unless it be an alteration product, must be as old as the Triassic rocks. We hope to be able to fix the age nearer than this, however, after an examination, with that object in view, of some of the facts presented by

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Prior to the publication of the authors' papers on these deposits, more had been written on this question than on any other connected with the deposits. So far as the writer has been able to learn there seems to be almost a general agreement, that these ores are older than a great part of the Permians. This, in fact, is proved by the existence of hæmatite fragments in the Lower Permian breccia. But how much older it is than this breccia is not so easily answered.

In a paper on the hæmatite ores of North Lancashire and Cumberland, read before the British Association at Leeds in 1858, Professor Phillips is reported to have said, that "the date to which it (the ore) could with most probability be referred was that of some part of the Permian deposits."

Professor Harkness and Sir Roderick Murchison, in a paper on the "Permian Rocks of the North-West of England:"[1] say,

[1] *Quarterly Journal, Geological Society*, 1864.

"The mode in which that valuable ore of iron, hæmatite, is found in pre-existing cavities of the carboniferous formation and sealed up by 'crab rock,' is a matter of great geological interest. Joints, fissures, and caverns were doubtless formed in the older rocks, antecedent to the deposition of the Permian strata, and in these, the ores of iron, so widely diffused throughout the Permian rocks, have in this portion of the north-western region assumed the characters of hæmatite. This circumstance justifies the inference, that these hæmatite ores are the result of an agency which ushered in the Permian epoch.

"The earlier Permian rocks of both England and Scotland are strongly impregnated with iron, their composition consisting principally of silica, and an oxide of this metal. This latter substance originated from the same source, which, during the commencement of the deposition of the Penrith sandstones, filled up the fissures in the carboniferous limestone. This conclusion is applicable not only to the Ulverston district, but also to that of Cleator, south-west of Whitehaven, where valuable deposits of hæmatite are also obtained from the cavities and fissures in the carboniferous limestone, which, at one time, was here covered over by an extension of those Permian breccias and sandstones now forming an escarpment, a short distance west from Cleator Moor."

The writer saw reason to dispute the conclusion of these authorities, that the crab-rock of Furness was a Permian breccia, and in a paper on "The Hæmatite Deposits of Whitehaven and Furness"[1] said that, "having carefully surveyed the whole district, he believed this 'crab-rock' belonged to the drift period, and not to the Permian system at all." This conclusion has since been supported by the map of that district, published by the Geological Survey. On that map no notice is taken of the "crab-rock," but surely there would have been, had the surveyors considered it to belong either to the Permains, or to any other group of rocks below the drift. This "crab-rock," therefore, affords no evidence whatever of the Permian age of the

[1] *Transactions Manchester Geological Society*, 1875.

hæmatite; it might, for anything this breccia proves to the contrary, have been deposited during the Triassic, or even during the Jurassic or Tertiary period.

Mr. E. W. Binney, in a paper entitled "A Glance at the Geology of Low Furness, Lancashire,[1] says: "The beds of iron appear to have been formed after the carboniferous limestone, and before the deposition of the upper new red sandstone." The same writer in a paper "On the Origin of Ironstones, and more particularly the newly discovered Red Stone at Ipstones, near Cheadle, Staffordshire, with some Account of the Ironstones of South Lancashire,"[2] says: "The position of the bed of hæmatite at Ipstones is between the upper part of the rough rock and the Woodhead Hill stone, somewhere near about the position of the nine-inch seam of coal in the author's section of the lower coalfield of Lancashire. In other districts where this little seam is found (and it is more constant in its thickness over a great distance than most other coals) some large deposits of carbonate of iron are met with in the shales above it, so iron then appeared generally present in the waters of the carboniferous sea, and the cause of the deposit at Ipstones being preserved from being converted into a protoxide, most probably arose from there being a less quantity of vegetable matter in the waters thereabouts than had been generally the case during the deposition of the carboniferous strata."

Again, in a paper "On the Age of Hæmatite Iron Deposits of Furness," read before the above-named Society, December 10th, 1867, Mr. Binney says: "When his papers" (the two quoted above) "were written, conclusive evidence could only be given of the age of the hæmatite iron of Ipstones, in Staffordshire, which was clearly interstratified in the lower coal measures, between the rough rock or upper millstone grit (of Professor Phillips and the Geological Survey), and the gannister coal.

[1] *Proceedings of the Manchester Literary and Philosophical Society*, 1848.

[2] *Proceedings of the Manchester Literary and Philosophical Society*, 1853.

Some years since, Mr. Bolton of Swarthmoor, near Ulverston, showed him, amongst other fossils, a beautiful specimen of *Sigillaria vascularis*, exhibiting both its external characters and its internal structure, quite as perfect in every respect as the specimens found in the gannister or hard coal at Halifax, or the bullion seam of Burnley, all converted into hæmatite iron. At this time no doubt existed in his mind of its having come from one of the Furness iron mines; *but Mr. Bolton could give him no proof of the exact locality where it was found.*"

Further on Mr. Binney writes (when referring to some specimens belonging to Miss E. Hodgson of Ulverston): "They do not exhibit their external characters so well as Mr. Swainson's (Mr. Bolton's) specimens do, but one is a *Stigmaria*, the root of *Sigillaria*, and another *Lepidodendron*, two common coal plants, which indicate the carboniferous age of the deposits in which they are found as clearly as any fossil organic remains can do.

"There is no doubt about Miss Hodgson's specimens; they came from the Water Blean mines, and plenty more may be obtained from the same place. They are all converted into good hæmatite iron, that substance having metallised them in a similar way, as we find plants in the coal-measures converted into the carbonate of the protoxide of iron, or carbonate of lime." And again: "The discovery of common coal plants, not only embedded in, but actually formed of, hæmatite iron, surely indicates the carboniferous age of the deposits in which they are now found as clearly as it well can be; for the plants must have been floated in with the water which brought the iron, or else they must have fallen into the cavities when such were open at the top, and the iron was in a soft state. Of course the occurrence of such plants as *Sigillaria*, *Lepidodendron*, and *Calamites*, occurring as they do in beds from the lowest to the highest carboniferous strata, would give little evidence of any particular part of that epoch; but the *Sigillaria vascularis*, so far as yet known, is confined to the lower coalfield, not far in geological position from the Ipstones hæmatite previously

alluded to, and the valuable clayband ironstones now wrought at Hazlehead west of Penistone. The deposits of hæmatite in Furness and Cumberland, found in hollows of the carboniferous limestone, and covered up by till, or 'pinel,' as it is locally termed, or more rarely by Permian breccia, are so much alike in all their characters, that if the origin and age of one of them are clearly proved, those of the rest must follow almost as a necessary consequence."

In the remarks that follow the writer will largely employ the arguments already advanced by him in his paper on "The Hæmatite Deposits of West Cumberland."

The fact of hæmatite being interstratified with the lower coal-measures at Ipstone, proves to Mr. Binney that that ore, at any rate, is of lower coal measure age. The deposits of Whitehaven and Furness he supposes to be of the same age, from the fact of a *Sigillaria vascularis*, converted into hæmatite, having presumably been found in one of the Furness deposits. But it has been seen that at Millyeat a bed of hæmatite is interstratified with the *upper* coal measures. Now that cannot possibly be of lower coal measure age; so that unless there have been two or more periods of hæmatite deposition in these districts, the other deposits found in them are not of lower coal measure age either.

In tracing the physical history of the Whitehaven district it is soon perceived that from the commencement of the carboniferous era to near its close, there was no great breach of continuity in the process of rock formation, but that from the bottom bed of limestone to the top of what the author calls the lower coal-measures, layer after layer was laid on in uninterrupted conformity. This is proved by the absence of overlapping and the comparative regularity that prevails in the thickness of the strata formed. The tilting and accompanying faulting of those rocks could not therefore take place before the period of upheaval and denudation, which is marked by the physical break that occurs between the lower and upper coal-measures. This being so, it follows, if the ore in the carboniferous limestone is of lower coal-measure age, as

Mr. Binney says, that these deposits must have been intersected by the faults alongside which they lie; but is this so? In Fig. 13 there are what may be looked upon as three distinct deposits of ore—e', e'', e''', the two first being on the north side of the fault and the last on the south.

Had these deposits been intersected by the fault—that is to say, had the ore existed there before the fault was formed, part of e' and e'' would have been found on the south side of that fault, and part of e''' on the north side of it. But this is not so; and therefore it follows that these deposits, at any rate, could not possibly be of lower coal-measure age—in fact, they could scarcely have been formed before the submergence which preceded the deposition of the Whitehaven sandstone, so that they are probably of the same age as the Millyeat ore. It will thus be seen that the deposits in both the upper and lower carboniferous rocks are younger than they are supposed to be by Mr. Binney; for what has been proved of the deposits shown in Fig. 13 is equally true of all the others in the same rocks, although it cannot be so directly demonstrated, for the simple reason that, in every other case, so far as the writer is aware, the throw of the fault is so large, that either the limestone in which the deposit occurs on one side is thrown off altogether on the other, or the pits working the deposit on one side are not sufficiently deep to enable the corresponding horizon to be reached on the other, or, if deep enough, are not on the right side of the fault.

Plate I. shows that those east and west faults which are up to the south are early Permian, their last movement having taken place since the deposition of the Whitehaven sandstone. The extent of that movement has not yet been ascertained; but it is certainly over thirty fathoms in some cases, for the great coal-measure fault, passing through the Montreal mines, has thrown the Whitehaven sandstone out altogether on the south. The principal north and south faults are also of an early Permian origin, but they have had a movement since the deposition of the St. Bees sandstone. In some cases this movement has amounted to 60 fathoms. Now, since the ore

was certainly deposited before this movement took place, it will be seen that alongside a north and south fault a deposit of hæmatite in the same bed of limestone may be very much higher on one side of that fault than it is on the other, and yet not be older than the fault, but simply older than the last movement of it.

The deposits in the granite, the Skiddaw slate, and the Coniston limestone are doubtless of the same age as those in the carboniferous limestone, although, at present, there seems to be no means of proving it; but it does not appear likely that there was more than one period of hæmatite deposition.

Altogether, it may safely be considered that the hæmatite of West Cumberland and Furness is older than the lower Permian breccia, but younger than the bulk—if not the whole—of the coal measures. The time during which it is possible for the ore to have been deposited is rendered, by the above limitation, very small geologically.

Mr. J. G. Goodchild, however, objects to this conclusion. In a paper on "Metalliferous Deposits" he says, after agreeing with the writer that the deposits are products of replacement, "From Mr. Kendall I differ, in referring the date of formation of the hæmatite to one later than that of the new red sandstone, as I regard the so-called pebbles of hæmatite that occur in many of the new red breccias and conglomerates, notably those of Somerset and north-west England, simply as pebbles of calcareous matter which have been subsequently converted into hæmatite by precisely the same means as those that have converted the carboniferous encrinites." Mr. Goodchild cannot be aware of the character of some of the hæmatite pebbles in the Permian breccia of these districts. They are quite rounded and smooth, which could scarcely have been the case had they been produced *in situ*, as suggested by Mr. Goodchild. There is not in the writer's mind any doubt that they have been subjected to the wearing action of both rolling and attrition since they became hæmatite.

The Limonites of the Forest of Dean and South Wales.

Mr. E. Rogers,[1] in the "Iron Ores of Great Britain," Part III., considers the Mwyndy deposit to be "the lower bed of the Permian series." This, although probably near the age of the ore, is clearly an error; for the deposit cannot, now that its nature is better known, be looked upon as a bed at all, but simply as an irregular deposit in the carboniferous limestone, as described in Part II.

The presence of limonite pebbles in the dolomitic conglomerate, overlying some of the South Wales deposits, shows that those deposits are *older* than upper Trias. Again, the manner in which the direction of parts of the deposits are, frequently, influenced by the joints in the carboniferous limestone shows that the ore was not deposited until the consolidation and jointing of that rock, that is, probably not before the close of the carboniferous period. These facts, taken in conjunction, render it almost certain that the age of the South Wales deposit is Permian. This conclusion may be extended to the Forest of Dean deposits, although, in that case, we have not the same evidence to enable us to fix the later limit; but the two sets of deposits are so much alike in most respects, and so near together, that it is exceedingly likely they are of the same age.

The Iron Ores of Cornwall, Devon, and West Somerset.

The evidence as to age is not very complete, but there can be very little doubt that the ores of these counties were deposited during Permian times. The dislocations along which many of them occur are post-carboniferous, and there are, in part of the area at least, fragments of limonite, presumably from these veins or others formed at the same time, included in the dolomitic conglomerate belonging to the upper part of the lower Trias. Seeing, moreover, that the Permian

[1] *Memoirs of the Geological Survey*, 1861.

was peculiarly an age of iron, the inference that these ores were deposited at that time is fairly warranted

THE LIMONITES AND SIDERITES OF ALSTON AND WEARDALE.

Professor Warrington Smyth[1] was of opinion that siderite was being formed at the present day, and in proof thereof he mentioned the case of an iron bar which had been found by Mr. Attwood partly coated with this ore. That, however, may be perfectly true, and yet afford no clue whatever to the age of the deposits under consideration. The manner in which "loffs" in the ore, lined with fluorite and other minerals, have been subsequently filled with siderite, shows that this ore has been formed in a small way, at any rate, since the bulk of it was deposited; but this is not by any means an uncommon phenomenon in ore deposits generally, and in all probability has arisen from a dissolution and redeposition of some small part of the original ore mass.

These ores, as we have seen in Part II., occur alongside faults which cannot be older than middle or late Permian, since they intersect the "Whin Sill," which is of early Permian age. This shows conclusively that the ores cannot be older than middle Permian, but how much younger they are is more difficult to answer, in fact so difficult, from the absence of evidence, that we are compelled to stop at probability. For aught that is known to the contrary, these ores may be of any age between Permian and recent; but when it is borne in mind that the former age was abnormally rich in ferruginous products, there is a strong inclination to fix upon that as the period in which these deposits originated.

THE ARGILLACEOUS IRONSTONES OF THE CARBONIFEROUS ROCKS.

It is very doubtful whether these deposits were contemporaneous with the shales in which they are embedded; indeed it is almost certain they were not; but there is no evidence

[1] *Quarterly Journal of Science*, vol. v., p. 36.

to show that they are of any other age. They may have been formed in carboniferous times or in any geological age since, so far as we know, so little evidence have we bearing on the question.

The Iron Ores of the Secondary Rocks.

These ores are younger than the rocks in which they occur, but that is practically all that can be said as to their age, in the present state of knowledge. To answer the question—"How much younger?"—further evidence is needed.

The Iron Ores of Antrim.

Being interbedded with rocks of lower Miocene age, but formed subsequently to those, they must be somewhat younger; but how much it is not possible, in the present stage, to say.

The Iron Ores of Spain.

Little can be said under this head. We only know that the Vizcayan deposits occur in rocks that are of Upper Cretaceous age, but we have no means of saying how much younger the ores are than the rocks in which they lie. Only one thing can we be sure about, and that is, they are younger. The same remarks apply to the archæan magnetites of Malaga. They may be very much younger than the rocks in which they occur, but even geologically we cannot fix their relative ages. They were certainly not contemporaneous with the rocks in which they are intercalated, as set forth in at least one important text-book. This is proved conclusively, by the ramifying strings and threads of ore which traverse the adjacent rocks, and *vice versâ*, as well as by the form of such deposits as that at Estapona.

CHAPTER II.

ORIGIN OF THE DEPOSITS.

ONE of the first and most suggestive facts which arrests our attention in the consideration of this question is the great variation that exists in the proportions of the several rock-forming minerals in ores from different geological horizons. This fact is set forth in the subjoined table of the average percentage weights of the more important non-metallic minerals usually associated with iron ores.

Description of Ore.	Silica.	Alumina.	Lime.	Magnesia.	Average of
1. Limonites of the inferior oolite	12·39	6·13	2·81	1·04	37 samples.
2. Limonites of the lias ...	11·29	8·47	6·05	1·31	21 "
3. Coal-measure ironstone ...	10·99	5·02	2·85	2·6	32 "
4. Hæmatite, West Cumberland	9·42	1·25	1·12	·19	78 "
5. Hæmatite, Furness ...	11·21	·73	1·17	·49	9 "
6. Limonite, Forest of Dean	17·93	2·85	1·9	·28	160 "

From this table it will be seen that the proportion of alumina, lime, and magnesia is much less in the ores found in the thick and comparatively pure limestones of the carboniferous limestone series than in the ores of the oolite, lias, and coal measures, which are associated with huge masses of shale and clay. The meaning of this will be apparent when we come to consider the origin of the different classes of ore. Let us begin with

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Various answers have been given to this question in relation to these districts. Mr. Binney,[1] in "A Glance at the Geology of Low Furness," says: "The quantity (of iron) in the iron mines of Low Furness is such as to indicate a proximity to the source whence it originated. It appears to have been thrown up by volcanic action, and then carried by some means into the valleys and fissures where it is now found. But whether the iron was injected into the places where it is now met with through the fissures immediately below, or was first mingled with the waters of the sea when they flowed through the fissures and caverns of the limestone, and gradually filled them up with the metallic matter held partly in solution, as Professor Sedgwick thinks, it is difficult to determine." Again, in his paper on the "Origin of Ironstones,"[2] Mr. Binney says: "After examining the beds of hæmatite found in the carboniferous strata in regular beds, as in the vicinity of Whitehaven and those at Ipstones, no one can doubt that they had their origin in volcanic vents and flowed into the waters of the sea, where they were deposited, layer by layer, with the argillaceous and silicious impurities found associated with them, like any other substance thrown down from suspension. This is evident from the beautifully laminated structure of the Ipstones bed."

Mr. William Brockbank,[3] in discussing this question, said: "In the porphyry of Bowfell there are large veins of true kidney hæmatite ore, and especially in the hollow or cleft between its two summits. The pike of Bliscoe in Langdale is deeply veined with hæmatite, and the Red Tarn behind its summit derives its name from the hæmatites which form its shores. Indeed, so rich are the veins of true hæmatite in the older rocks at the head of Langdale, that it has been in prospect to carry a railway up to work them.

[1] *Manchester Literary and Philosophical Society*, 1847.
[2] *Manchester Literary and Philosophical Society*, 1853.
[3] *Transactions of the Manchester Geological Society*, vol. xiii., part 9.

"There are true hæmatites near the summits of Scawfell. The 'Screes' at Wastwater are veined with them; Red Pike near Ennerdale gets its colour and name from hæmatite ore; and in this locality it was smelted by the Romans. All these are in the syenite, porphyry, and other oldest igneous rocks. There are very rich mines now worked in clay slate at the foot of Grasmere, and there is a railway making up the Ravenglass valley to convey the ore from mines which occur in veins in the granite and other older rocks. At Lindal, in Cartmel, a vein of hæmatite can be seen between the clay slate and limestone, and all round Arnside Knott are true veins of hæmatite much altered by heat. These, then, are instances of the occurrence of hæmatite ores directly from their parent source, and in my opinion they prove the origin of hæmatite ore to be igneous." Further on, Mr. Brockbank is reported to have said: "Now, Professor Phillips describes the great igneous granite and syenitic masses about Scawfell and Bowfell as having been in fusion since the deposition of the clay slates, because the latter are everywhere found to be indurated and metamorphosed by their action. It is these very igneous rocks which now bear the hæmatite veins above described, and we thus have a direct clue to the origin of the rest. Bearing in mind that the clay slates of Dent were not yet above the level of the ocean, we may picture these igneous centres pouring out the ferruginous stream of lava-like matter seawards, where it would meet the carboniferous rocks tilted and fissured, and thus fitted to receive it. Then followed the Permian era, and after long ages the great final upheaval by which the outliers of the Lake District, Dent-fell and Cold-fell, in the Whitehaven district, Blackcomb, in Millom, Ireleth and High Haume, in the Furness district, were pushed through, tilting the carboniferous rocks and again fissuring them in all directions. This, again, would not be the work of a moment; but it would in all probability occupy an epoch giving time enough for denudations and the wearing out of the subterranean watercourses or caverns which became filled with the hæmatites wherever circumstances were favourable."

Mr. John Plant,[1] quoting Professor Newbury, geologist for the State of Ohio, said: "Red hæmatite consists mainly of peroxide of iron, the ores of which have been plainly derived from limonite (brown hæmatite) by loss of the combined water. The famous Cumberland ore of England is a typical example of this variety. This was once a hydrated sesquioxide deposited from water in concretionary masses, and having a fibrous radiated structure. Similar ore is found in various parts of the world; wherever, indeed, a limonite has been subjected to metamorphic action by which its water is removed, hæmatite is found in concretions or botryoidal masses in sand or clay, filling crevices, pockets, or basins, or incrusting slopes, wherever, indeed, chalybeate waters have precipitated their iron. It is often associated by limestone rocks because they are more easily than others dissolved by atmospheric water, so as to form caverns and galleries where the ore may accumulate, and also because the limestones contain much iron, and in the removal of the carbonate of lime by solution the oxide of iron is left, and, to a certain extent, takes its place."

Mr. David Forbes[2] is reported to have said that "the direction of vein-like deposits is due to their being formed in pre-existing fissures into which hæmatite has been injected. When hæmatite is found in caverns it has been washed in by water."

Professor Harkness and Sir Roderick Murchison, in a paper on the Permian rocks of the north-west of England —which has been already quoted—say: "The mode in which that valuable ore of iron, hæmatite, is found deposited in pre-existing cavities of the carboniferous formation, and sealed up by 'crab rock,' is a matter of great geological interest. Joints, fissures, and caverns were doubtless formed in the older rocks antecedent to the deposition of the Permian strata, and in these the ore of iron so widely diffused throughout the Permian rocks has in this portion of the north-western region assumed the characters of hæmatite. This circum-

[1] *Transactions of the Manchester Geological Society*, vol. xiii.
[2] *Quarterly Journal of the Geological Society*, May 1876.

stance justifies the inference that these hæmatite ores are the result of an agency which ushered in the Permian epoch. The earlier Permian rocks of both England and Scotland are strongly impregnated with iron, their composition consisting principally of silica and an oxide of this metal. This latter substance originated from the same source, which during the commencement of the deposition of the Penrith sandstones filled up the fissures in the carboniferous limestone. This conclusion is applicable, not only to the Ulverston district, but also to that of Cleator, south-east of Whitehaven, where valuable deposits of hæmatite are also obtained from the cavities and fissures in the carboniferous limestone, which, at one time, was here covered over by an extension of those Permian breccias and sandstones now forming an escarpment a short distance west from Cleator Moor."

It will have been noticed that all these explanations require the existence of caverns and fissures in which the ore could accumulate. But those who have followed carefully the remarks on the inner nature of the deposits in Chapter II., Part II., will probably be convinced, as was first pointed out by the author in his paper on the "Hæmatite Deposits of Whitehaven and Furness,"[1] that the deposits were not formed in either caverns or fissures. Let us consider Fig. 16. It must be clear to every one that the ore shown there could not by any possibility have been formed in a cavern. The thin bed of shale (*f*) running through the ore also passes, without interruption, right on into the side rock *c* and *c'*; in fact, it is interbedded with the limestone, and therefore must have been formed at the same time. Now, such being the case, it is evident that the ore, which this parting intersects, cannot have been thrown down in a cavern previously formed in the limestone, for if so, this thin parting, being now in the same relative position to the surrounding rocks as it was when first deposited, must have stretched across that cavern, and must consequently have been able to stand without intermediate support across an opening

[1] *Transactions of the Manchester Geological Society*, 1875.

five or six fathoms wide. Such a thing is, however, altogether impossible; for it must be evident to any one that the parting must fall if the support were taken from it, as it must have been had the parting spanned a cavern. Besides, it has already been seen that the deposition of the ore was preceded by the faults alongside which it occurs, so that the shale-parting, *f*, would receive no support from the rocks on the west side of the deposit, as it would then have no connection with them, having been severed from them some time previously by the fault which occurs on that side of the deposit. It must, therefore, have stood out from the side of the cavern like a cantilever. That is, however, quite impossible; so that it may be said with certainty that the ore in question was not deposited in a cavern. The same argument holds good for the deposits shown in Figs. 14 and 15.

The shale nests and partings mentioned as occurring in the ore were evidently formed before the carboniferous limestone had been disturbed, because the laminations of the shale in each case are parallel to the bedding of the rocks surrounding the ore. But it is known that the ore was not deposited until after the limestone had been tilted and faulted. It is therefore clear that these nests and partings existed before the ore was thrown down, which shows that it could not have been laid in a cavern, or the shale nests would have had to float in air.

This conclusion is further supported when we come to the consideration of deposits which have roofs of shale. No one at all acquainted with such-like deposits could for a moment suppose that the ore in them had been deposited in a cavern. If, at the present time, in working the ore, but a few square yards of these shale "roofs" be left unsupported, they very soon fall away. How could they have stood, then, before the ore was deposited, as the "roofs" of immense caverns several acres in extent? It will be seen by an examination of the sections (Figs. 13, 16 and 17) that these shale beds could not possibly have been deposited after the ore, for they are interbedded with the limestone, and, consequently, contemporaneous with that rock.

Even deposits with strong stone "roofs" like that at Parkside (Fig. 7), could not have been formed in a cavern. Any one who has gone through the Peak cavern in Derbyshire, which is the largest in England, must have been struck by the immense number of limestone blocks which have fallen from the roof, and now lie in piles upon the floor. Yet the size of the largest chamber in that cavern is, as it were, a mere "lough" compared with that which would be necessary to hold the Parkside deposit; in fact, it is not one-fortieth of the area. Then, the great regularity of the "roof" of the Parkside deposit, and the absence of roof-stone fragments on the "floor" (both contrasting strongly with the Peak cavern), prove conclusively that that deposit is not a filled cavern.

What has been said of some of the deposits is equally applicable to the others, as could easily be demonstrated were it necessary to multiply examples; so that it may be with every confidence asserted that, at any rate, the ore in the carboniferous limestone was not deposited in caverns.

That the Millyeat ore is not a cavernous deposit will probably be admitted by all, notwithstanding its great resemblance, except in thickness, to deposits which would generally be looked upon as having been formed in a cavern.

Let us now see how far the fissure idea is supported by the deposits in the Skiddaw slates, the Ennerdale syenitic granite, and the Eskdale granite. It has been seen that the ore in these rocks does not occur continuously in the veins, but that each vein consists of a number of "bunches" or "bellies" of ore, which are connected by what the miners call a "leader." Many of these "bunches" present an area of several hundred square yards when viewed in longitudinal section.

Now, in extracting the ore, especially at Kelton Fell and Knockmurton, the miners find it necessary to use a large quantity of timber, in order to keep up the "hanging cheeks." When "stoping" they cannot leave many yards of the "cheek" unsupported or it would very soon fall away. How could it have ever so stood, then, for hundreds of yards, whilst the ore was being formed, if it was deposited in an open

fissure? Clearly the sides must have fallen away. That they have not done so is a proof that the ore was not deposited in a fissure.[1] Besides, the section given in Fig. 2 bears no resemblance whatever to a filled fissure; yet many similar forms may be found in these veins.

The same thing cannot be shown so directly in the case of the Water Blean ore, but the author's impression is that it, like the others, was not deposited in caverns, as will appear further on.

The effect of the foregoing conclusions is to show the inadequacy of all those attempted explanations, of the origin of these deposits, which involve the assumption of pre-existing caverns and fissures. Those who have not observed the facts on which these conclusions are based may fail to feel the full force of the argument, so that it may not be undesirable to look at the question from another point of view.

The fact which chiefly inclines writers and thinkers to the idea that these deposits are filled caverns and fissures is, that they present external forms exactly similar to what they would have had if the ore had actually been placed in such receptacles; but it must not be forgotten that similarities are not identities. Moreover, it will be shown, further on, that precisely similar forms might be imposed upon the deposits by an entirely different process, and one which is consistent with the remaining facts. The only other feature of the deposits that has been put forward as suggesting that they are filled caverns is that sometimes, in working the ore, the miners strike into a "lough," every side of which, except that against the ore, is limestone or "whirlstone." This, it is said, is part of the cavern that has not been filled. Now if these "loughs" always occurred at the top of a deposit, there might be some force in the assertion; but seeing that they are found at the bottom and sides as well, this argument is completely negatived, for those at the lower levels would surely have been filled.

[1] The author has extended this argument to all mineral veins, in his paper on "The Mineral Veins of the Lake District," *Transactions of the Manchester Geological Society*, 1884.

Having shown that the ore could not possibly have been deposited in caverns and fissures, and thereby exposed the insufficiency of previous explanations, it may seem unnecessary to follow them further; but in order to show their general incompetence the writer will make a few observations on the modes in which it is supposed the caverns and fissures were filled. Mr. Binney and Mr. Brockbank are of the opinion that the ore is of volcanic origin, and that it was either injected into the places where it is now met with, through fissures immediately below, or it was first mingled with the waters of the sea and then thrown down as a sediment. Referring to Fig. 1 and its description, it will be seen that everything in the vein is arranged in lines parallel to the "cheeks," as shown by the kidney ore c″. In the veins at Kelton and Knockmurton the same thing is seen. Now, sedimentary deposits do not take place in this way except to a small extent; they seek the lowest level possible. Moreover, no deposits are known which are formed, to any extent, on such steeply inclined and overhanging faces as the "cheeks" of veins, except chemical precipitates. That the ore was not injected directly from below into fissures is clearly shown by the gash-like form of the veins, the ore generally becoming less and less in depth. The reverse would have been the case had it so come from below; for, as the distance from its source increased, the work to be done by the moving ore would be increased, and consequently the available energy would become less and less; so that as the ore moved upward its dimensions would be gradually reduced. If, therefore, it had been injected from below in a molten mass it would have become thicker in depth; but exactly the reverse is the fact. Again, it surely is to be expected that there would be present some evidence of the calcining effect of these masses of molten matter, such as a hardening of the enclosing rocks; but this is not so. It may therefore be taken for granted that the ore in these veins was not deposited in a molten state, nor indeed as a sediment from water, for the reasons given above. Neither was the ore in the carboniferous limestone deposited in either of these ways, as is shown by the existence in it of fossils

belonging to, and in some cases consisting of, that rock. Besides, the "growing together" of the limestone and the ore, in these deposits, as well as in those at Water Blean, in the Coniston limestone, is quite opposed to either the igneous or sedimentary theories.

The views of the late Mr. David Forbes, so far as they can be gathered from his few remarks on the subject, appear to have been somewhat similar to those of Mr. Binney and Mr. Brockbank, so that it is not necessary to notice them separately; neither is anything special found in the opinions of Professor Newberry, Sir Roderick Murchison, or Professor Harkness. The author will, therefore, proceed to give his own explanation of the origin of the deposits.

"It is known that when certain elements, or combinations of those elements, are brought into contact under suitable conditions, a chemical reaction takes place between them. For instance, if a piece of chalk be dropped into a solution of perchloride of iron, there at once sets in a reaction between them; part of the chalk is dissolved, and a red precipitate thrown down in its place. In time the chalk would disappear altogether, and nothing be left but this red precipitate. Now, that seems to be the process by which the hæmatite deposits were produced. Applying the explanation first to the limestone deposits, and especially to that shown in Fig. 16; and supposing that *d* and *d'* were originally beds of limestone with the shale parting *f* between them, and that, by a process similar to that mentioned in the above experiment, these limestone beds were replaced by ore, the reason why the shale parting has never fallen away becomes apparent; for, of course, it would never be left unsupported. As the limestone was dissolved the ore would be thrown down in its place. The same explanation shows why the shale partings in the ore, in Figs. 14 and 15, and the shale 'roofs' in Figs. 13, 16, and 17, have not fallen away. It shows, too, how the nests of shale, which certainly were formed before the ore, have come to be in the apparently anomalous position in which they are found. As already stated, these nests must have been deposited before the rocks were tilted, and therefore

before the ore was deposited; for the latter did not take place until the rocks had assumed very much of their present position. The shale must have been deposited along with the limestone, but offering, as it would, a greater resistance to the iron solution the limestone around it has been removed and replaced, whilst the shale has remained and been but very little altered." [1]

Again, it will be seen how it is that the "roof" of such deposits as that at Parkside has not fallen; and also, why, in the Whitehaven area, only the deposits in the fourth, fifth, sixth, and bottom limestones have shale partings. The first, second, and third limestones not being split up by partings, like those below, no partings could be expected in the ore which had replaced those limestones.

The north and south direction of the deposits, when not interfered with by east and west faults, the occurrence of "guts" in the "roof" of such deposits as that at Fletcher pit, and the "rolls" in the "floor" of the Parkside deposit, as well as the general cavern-like form of the deposits as a whole, can each and all be satisfactorily explained on the supposition that the ore resulted from a replacement process. At one time or another the author has examined nearly all the principal caverns in England with the view of seeing what light they threw upon these hæmatite deposits, and he invariably found that the different chambers of those caverns are hollowed out on the lines of jointing, sometimes following one set of joints, and sometimes another; but the largest chambers were along those joints which run nearly north and south. This may be well seen in the Peak cavern, in Derbyshire, the three largest chambers of which—the Victoria chamber, the great chamber, and the chamber at the entrance—where the twine-spinning is carried on—are on the line of north and south joints. Then again in the Blue John mine, in the same county, the beautiful chamber known as Lord Mulgrave's dining-room, and the

[1] This explanation was first put forward by the author in 1874, in a paper on "The Hæmatite Deposits of Whitehaven and Furness," *Transactions of the Manchester Geological Society*, 1875. Since that time it has been adopted by several writers in notices of these deposits.

still larger chamber at the end of the cavern, are both on the line of the north and south joints. So also are the largest parts of Poole's cavern, near Buxton. In the Brixham cavern in Devonshire, the correspondence of the different chambers with lines of jointing may be very distinctly seen. It is also well displayed in Kent's Hole; and in the author's paper on "The Hæmatite Deposits of Whitehaven and Furness," the same was shown to obtain in a cavern at Stainton, in Furness.

The explanation is probably this: carbonated water has gained access to the limestone along the joints, and dissolved the limestone, particle by particle, on those lines, until at length the widening joints united and formed the present caverns.

The action of a solution of iron, such as has been named, would be similar to that of carbonic acid in cavern forming, only, as the limestone was dissolved, peroxide of iron would be thrown down in its place. Thus it may be seen how it is that the "guts," the rolls, and the deposits as a whole are parallel to the joints. But why they kept to those that are nearly north and south cannot be explained so clearly, unless it is that the joints having this direction are stronger and more persistent. That would certainly account for it, and may probably be considered the correct explanation, for, as a matter of fact, the north and south joints are more persistent; but still east and west caverns are found, so that east and west deposits of iron might, with reason, have been expected. Of course very much would depend upon the manner in which the acidulated water obtained access to the rocks; and the author hopes to be able to show, further on, that it was this which determined the parallelism of the deposits.

The growing together of the ore and the stone is also explained by the replacement process. Being an operation which requires some time for its completion, it will of necessity only be complete where that time has been sufficient. From there to the unaltered stone it will be less and less complete—that is to say, between the ore and stone there will be a sort of "No man's land," occupied partly by stone and partly by ore,

the one increasing as the other diminishes; each retaining less of its peculiar character as the distance increases from its native land. The greater resistance presented to the iron solution by the silicious portions of the limestone is no doubt the reason they were left in masses in the deposits as now found. The form of these silicious masses would doubtless, in many cases, affect the shape and direction of the deposit, as the iron solution would act more easily on the limy portions than on them. This is probably the reason that the sides of the ore sometimes take very peculiar and irregular turns. For the same reason, the shale and sandstone forming the roof and sole in many deposits would not be replaced. The softer nature of the ore adjoining some shale beds is probably due to the admixture of shale with the limestone which the iron replaced, for the change from limy to argillaceous conditions would no doubt be somewhat gradual. The shale thus incorporated with the limestone, being less easily acted upon than the latter rock, remains mechanically mixed with the ore, rendering the latter soft in proportion to the quantity of shale it contains.

The laminated nature of some of the ore near the stone, and the alternate hard and soft beds sometimes met with, are both easily explained by the replacement process, as is also the occurrence in the ore of fossils—some converted into hæmatite—belonging to the carboniferous limestone. These fossils, like the shale beds in the ore, are an insurmountable obstacle to all other explanations, but to this they offer no difficulty whatever; in fact, they are another proof of its truth.

The existence of loughs and microscopic cavities in the ore is altogether incompatible with the supposition of its being a sedimentary deposit. They might occur in an igneous formation, although it is very unlikely that they would have their present form, but that such was not the mode in which this hæmatite originated is clearly shown by the presence in it of the shale beds above alluded to. Now, replacement pseudomorphs of hæmatite after calcite have precisely the porous appearance presented by the hard ore of these districts, a fact

which renders it still more probable that the deposits originated by a process of replacement.

The average composition of the hard blue-purple, or of the softer reddish-purple ore yielded by any deposit, may perhaps be expressed as follows :—

Peroxide of iron by weight 85 per cent. (equal to 59·5 per cent. of metallic iron).

Foreign matter by weight 15 per cent.

The specific gravity of peroxide of iron is about 5, and the average specific gravity of the associated foreign matter may be taken at about 2·24, so that the relative volumes of the two sets of material existing in the ore may be taken as 170 is to 67—that is to say, in 237 cubic feet of solid ore 170 feet will be peroxide of iron and 67 feet foreign matter. But it is found that about one-sixth of the bulk of a deposit of hard ore must be allowed for loughs, which are either filled or empty ; in other words, only five-sixths of such a deposit can be taken as ore. It appears, therefore, that in any deposit of hard hæmatite, measuring say 999 cubic feet, the volume is made up as follows :—

	Cubic Feet.
Peroxide of iron	598
Foreign matter	235
Loughs	166
Total	999

Thus it is apparent that, in a deposit of hard hæmatite, little more than half the volume of the ore (including loughs) is occupied by peroxide of iron, the remainder consisting of loughs and foreign matter. This foreign matter was probably deposited after the ore, and so filled up the minute pores which once existed in it ; just in the same way as many of the large loughs have been subsequently filled, whilst others are but partially so.

The replacement of limestone by hæmatite [1] may be effected

[1] As bearing on this question, it may be mentioned that in the Jermyn Street Museum there is a pseudomorph of hæmatite after calcite, from Parkside mine, Frizington.

in several ways in the laboratory; but, most probably, in the case of the deposits under consideration, it resulted from the action of an aqueous solution of either perchloride of iron or of bicarbonate of iron.

The reaction which ensues when an aqueous solution of perchloride of iron is brought into contact with limestone as is follows:—

$$Fe_2Cl_6 + 3\ (CaCo_3) = Fe_2O_3 + 3\ (CaCl_2 + Co_2).$$

Or, in other words peroxide of iron is precipitated, calcic chloride is held in solution, and carbonic acid gas given off. If the reaction takes place at an elevated temperature the hydrated precipitate may be altered to anhydrous hæmatite. In "Dana's Descriptive Mineralogy," fifth edition, p. 168, it is stated that "E. Davies has shown that the ordinary precipitate of hydrate of iron, on being boiled in water, may have its water reduced to 3·52 per cent. (*Journal of the Chemical Society*, 2, 4, 69)," and Rodman (*l.c.*) has by the same method reduced it to 2 per cent., showing that the water varies with the temperature of origin, and as Davies observes, "no great heat is needed to make thus anhydrous hæmatite."

In Watt's "Dictionary of Chemistry" (1875 edition), vol. iii., p. 395, more precise information on this head is given in the following statement: "Ferric hydrate gives off part of its water between 80° and 100° C., and the whole at a red heat; it is also completely dehydrated by heating it from 160 to 200° C., with a saturated solution of chloride of calcium or chloride of sodium." By the above reaction, as already mentioned, a solution of chloride of calcium is produced, which needs only to be heated and the precipitated peroxide of iron would be deprived of its water. The manner in which the solution was heated will be noticed hereafter, but it is probable that a much less temperature than that mentioned above, if continued for a great length of time, might have the same effect.

By the action of bicarbonate of iron on limestone there results:—

$$FeC_2O_5 + CaCO_3 = FeCO_3 + CaC_2O_5.$$

In other words, carbonate of iron is precipitated, and bicarbonate of lime is held in solution. The conversion of the carbonate into the peroxide of iron is effected as follows :—

$$2\ (FeCO_3) = Fe_2O_3 + CO_2 + CO.$$

Two volumes of the carbonate of iron being required to produce one volume of hæmatite, there is a loss from the evolution of carbonic acid and carbonic oxide of nearly one-third of the weight.

These reactions and changes necessitate the following relation in the volumes of hæmatite and limestone. From a solution of perchloride of iron 999 cubic feet of limestone would precipitate only 290 cubic feet of hæmatite of the ordinary density, but it would precipitate a larger volume if the density were reduced. From a solution of bicarbonate of iron 999 cubic feet of limestone would precipitate 438 cubic feet of hæmatite. This quantity is so much nearer than the previous one to the relative volume of peroxide of iron actually found in the deposits, that, from these considerations alone, it might seem more probable that the replacement had been effected by means of a solution of bi-carbonate of iron rather than by a solution of perchloride of iron; but there are other reasons which necessitate the rejection of that supposition, as will hereafter appear.

It has been clearly shown that both in Furness and West Cumberland, the hæmatite was deposited at a time marked by great volcanic activity; that is to say, simultaneously with the formation of the early Permian faults which intersect the carboniferous limestone. This connection, of itself, suggests that the original source of the iron was volcanic; but there are other reasons which point much more directly to that conclusion. Early Permian faults, it is known, occur everywhere throughout the carboniferous band which encircles the Lake District, yet it is only at three points in that band,—viz., Whitehaven, Millom, and Furness—that hæmatite has been found in large quantities. Now at each of those points the Skiddaw slate, which is the lowest known stratified rock of the

district, has been brought up to the surface. It has occupied that position, too, since pre-carboniferous times; for the carboniferous limestone reposes on it at Cleator, at Millom, and in Furness. Without assuming anything so extremely uncertain as that the earth's interior, during Permian times, was in a fluid condition, it seems perfectly legitimate to infer that the violent fractures and dislocations which then took place resulted from great internal pressure, due to a locally elevated temperature. That being so, is it not exceedingly probable that these fractures and dislocations would be accompanied by certain volcanic emanations? And seeing that the earth's crust would be thinner at those points where the Skiddaw slate was on the surface than at other points where it was covered by rocks of a later age, and also that, at the former points, the uplifting action was greatest, and therefore the fractures and dislocations would be greatest, it follows that there the volcanic emanations would be most abundant.

The way in which the hæmatite deposits are clustered in the neighbourhood of the older rocks of Haume, Blackcombe, and Dent, points clearly to the source of the iron. It may be said, of course, that they simply indicate that there the limestone was more broken up during the upheaval than it was farther away, and that, therefore, it would be more readily acted upon by any solution of iron brought into contact with it, no matter whether that solution came from above or below. But that would not be so, as will be shown hereafter. Besides, it seems altogether impossible that the iron solution can have come from above, notwithstanding that the deposits, as a rule, decrease in size downwards. Where could it come from above? There were no overlying rocks then containing iron, as most of the upper carboniferous strata had been removed by denudation; and if the iron solution had come along the surface from a distance, surely it would have found its way, as liquids do now, along valleys and other similar depressions in the ground, and would consequently attack the limestone along those valleys, so that there should be some intimate connection between the old valleys and the present

hæmatite deposits; but no such connection is found. On the contrary, some deposits occur on ridges separating valleys, others on hillsides, and bearing in mind that the physical features of a district may have been greatly altered since the Permian era, yet it is difficult to conceive how, or by what means, the face of these districts can have been so changed in certain parts, that a valley exists now where there was formerly a hill, and *vice versâ*.

Again, if overlying rocks had been the source of the iron, it might be expected that ore would more frequently be found in the beds of limestone, and other rocks near the surface, as they would first intercept the descending solution. It might also be expected that deposits found in the neighbourhood of Urswick would be quite as large as those found nearer Haume. That the fractures in the rocks near Haume were larger than at Urswick matters little; for the merest joint at either place would soon be widened by the action of the iron solution, and the precipitated material would for a long time be so porous that it would offer very little resistance to the percolating waters, so that a difference of a few inches in the width of the primary joint would not affect the ultimate size of a deposit. The latter is rather a question of circulation, for it is quite clear that the more rapidly, within certain limits, a mineral solution passes through the rocks, the greater, in any given time, will be the precipitate resulting from the chemical action of that solution on the rocks through which it passes. Now, there might be a better circulation at Urswick than near Haume; at any rate, it is impossible to say that it was not quite as good, nor is it possible to show that the conditions promoting circulation were better at the one place than at the other. But there is another difficulty in the way of supposing the iron in these deposits to have come from above. Ordinary river water contains the merest traces of iron. Spring water, as a rule, not more than 1 part in 400,000. Chalybeate springs, sometimes, only hold as much as 1 part in 3,500, but they soon deposit a large proportion of it on coming to the surface.

If the salt of iron which effected the replacement be supposed to have come from below in a gaseous condition, and to have been dissolved before reaching the surface in the waters circulating through the rocks in the neighbourhood of Haume, Blackcombe, and Dent, where, as already pointed out, it was most reasonable to look for volcanic emanations, then the whole of the facts presented by the distribution of the hæmatite deposits of these districts become as simple and as easily understood as any other geological proposition. It is known that perchloride of iron dissolves in water with considerable evolution of heat, so that there would be the high temperature which it has been shown is necessary for the dehydration of the precipitated peroxide of iron. Then again, circulation being, as a rule, greater along lines of fracture than through the body of the rock, the occurrence of deposits by the side of faults is easily understood; and since the iron solution would attack the limestone as soon as it was brought into contact with it, and as it would be most readily brought into such contact along lines of fracture near its source, the reason for the localisation of the Furness deposits around the high ground at Haume, and along the two main fractures traversing the district, is at once apparent. By the time the solution, in its course through the rocks, reached Urswick, and the more eastern parts of the district, it would be robbed of most of its iron.

At Millom and Cleator the limestone band is so narrow that it is impossible to say whether or not there is a corresponding diminution in the size of the deposits, as the distance from the source of the iron increases. But in viewing the deposits in this connection, there naturally arises one most important question: Why is it, seeing that the carboniferous limestone is resting on the Skiddaw slate all the way from Egremont to Cockermouth, that hæmatite occurs most abundantly between Egremont and Rowrah? The explanation of that fact is probably as follows: The boundary between the Skiddaw slate and the large area of volcanic rocks on the south is known to be a faulted boundary. There is thus adjacent to the

Whitehaven hæmatite area at least one important fracture in these older rocks. Then again, from Egremont to Rowrah the carboniferous limestone is very much faulted, whilst between Rowrah and Cockermouth very few faults occur. These facts seem to indicate, that the uplifting action which produced the faults was greater near Egremont than in the direction of Cockermouth, and therefore, in addition to the rocks being more seriously dislocated at the former than at the latter place (thereby facilitating, to a greater extent, the action of the aqueous solution on the rocks), there would be a greater number of passages formed for the escape of the iron from below. So that, whether attention is turned to the distribution of the deposits in the Whitehaven district or of those in Furness, the suggestion is irresistibly forced upon us that the source of the iron was volcanic.

The gradual diminution downwards in the size of the deposits is probably explained by the fact that the circulation of underground water is greatest near the surface, and that it gradually diminishes downwards until a plane is arrived at where there would be no circulation at all but for differences of underground temperature. This downward diminution of circulation must necessarily produce a downward decrease in the precipitate, resulting from the chemical action of any mineral waters passing through the rocks. Thus the wedge-like form of mineral veins is not, as is often supposed, a proof that they are filled fissures, but is a natural consequence of the differences in the circulation of underground waters.

The *source* of the iron being most probably volcanic, it is not likely that the replacement was effected by a solution of carbonate of iron, as that salt is easily decomposed by heat, and is, therefore, not found among volcanic emanations; but the perchloride of iron is one of the commonest of volcanic products. According to the preceding calculations, however, it appears that a deposit of hæmatite produced by the action of perchloride of iron on limestone, would only contain about half as much perchloride of iron as is actually found in the deposits of West Cumberland and Furness. But it must be

borne in mind that perchloride of iron has the power of holding in solution a considerable quantity of peroxide of iron, which, when the critical stage is reached in the reaction, is deposited along with the proportion of iron locked up in the perchloride; so that the deficiency indicated by the calculations may have been supplied in that way, or it may have been precipitated by lime or other salts in the water. In Watt's "Dictionary of Chemistry," 1875, vol. iii., p. 379, there occurs the following interesting statement on the solubility of peroxide of iron in perchloride of iron :—

"Soluble ferric oxychlorides, or basic chlorides, are obtained by adding recently precipitated ferric hydrate to aqueous ferric chloride. The hydrate dissolves in considerable quantity, and a deep red solution is formed containing from five to six or seven molecules of ferric oxide to one molecule of the chloride. The solutions may be heated or diluted with water without decomposing; those which contain the larger quantities of oxide deposit a portion of it, however, on the addition of certain salts, and when evaporated leave residues which do not re-dissolve in water. Compounds containing not more than 10 at Fe_2O_3 to 1 at Fe_2Cl_6 are, on the contrary, perfectly soluble in water after evaporation. (Phillips' *Phil. Mag.*, [3] viii., 406; Ordway *Sill. Am.* [2] xxxi., 197; Béchamp, *Ann. Ch. Phys.* [3] lvi., 306, lvii., 296.")

The sand and clay, so common in the Furness deposits, have clearly been deposited in loughs and caverns made in the limestone subsequently to the formation of the ore. The porous nature of the ore and its proximity to the surface, in such deposits as contain clay, would favour the admission of carbonated waters to the limestone surrounding it. Thus, caverns would be formed on the outside of the ore, which would need only to be filled with argillaceous and arenaceous materials to present the appearance of the pockets of sand and clay, which are found along the outside of the ore in the dish-like deposits. It is not a little interesting to contrast the heterogeneous character of the materials contained in these cavernous deposits with the complete absence from the ore of any foreign matter whatever, except such as may have been introduced chemically.

The broken nature of the ore found in nearly all the

shallow deposits of Furness is probably the result of some action that has taken place since the ore was consolidated. This is shown by the occurrence in the deposits of broken pieces of hard ore having a kidney-like form where there is now no lough, nor any indication of one, but the kidney ore itself. This result might have been brought about by the intense frost which prevailed during the glacial period. Water collecting in the loughs and pores of the ore, becoming frozen, would, if there were cavernous spaces or caverns filled with soft material round the outside, in all probability break the ore to pieces, as then the resistance to outward pressure would be little, if any, more than the tensile strength of the ore; or, it may be that the breaking up of the mass is due to the dissolution of innumerable small pieces of limestone originally locked up in the ore.

The clay which is found in the interstices of the broken ore has probably been carried down by water, recently, from the overlying glacial deposits.

In applying this explanation to the Millyeat ore, the nature of the bed before the replacement was effected cannot positively be pointed out; but from the thin irregular layers of limestone found in it, and the large quantity of lime which exists in a diffused state in some of the poorer ore, it seems extremely probable that it was originally a limestone. The same may also be said of the nodules in the millstone grit.

As regards Water Blean deposit there is a difficulty. Mr. Binney (as already mentioned) states that he has seen several fossil coal plants converted into hæmatite, which had come from this deposit. Now if the ore had replaced the original limestone, the supposed coal plants must have been imbedded in that limestone. That is, however, impossible, seeing that the limestone is of Silurian age; so that it must be concluded either that coal plants have not been found in the deposit at all, or, if so, that the ore was not formed by replacement. The author chooses the former alternative, for, as already stated, he does not believe that the structures referred to by Mr. Binney are plants of any kind, but simply what is known as "ring ore";

whilst the "growing together" of the limestone and ore, in these deposits, exactly as is seen in the carboniferous limestone deposits, convinces him fully that this deposit, like the others, was formed by replacement.

The veins in the granite, syenite, and Skiddaw slate are also more easily explained on the assumption that they were formed by replacement, for then the difficulty of keeping up the hanging wall whilst the ore was being deposited has not to be contended with, as is the case when the ore is supposed to have been deposited in fissures. Besides, by this supposition, there is an easy explanation of the occurrence of ore in such forms as shown in Fig. 2, of those pieces of slate in the veins of Kelton and Knockmurton, and of the transition from granite to ore, mentioned as sometimes occurring in the veins of Eskdale; whilst every other feature of these veins may be more simply explained by replacement than on the assumption that they are filled fissures. The substitution in this case was probably effected indirectly, the place of the original rock being first taken by dolomite, which was subsequently removed and replaced by hæmatite. Veins of dolomite are not uncommon in the Ash rocks of Eskdale, and they present all the features of hæmatite veins—the horses, the loughs, and the same laminated appearance. From the manner in which the dolomite of these veins is traversed by strings of hæmatite, it is clearly shown that the former mineral was in the vein first. If, therefore, it be assumed that all hæmatite veins in argillaceous and silicious rocks were once veins of dolomite, their replacement would easily be explained in the manner already described when speaking of the deposits in the carboniferous limestone. This suggestion is to some extent borne out by No. 1 analysis of ore, from Nab Ghyll vein in Eskdale, showing as it does 23·18 per cent. of lime, and 9·04 of magnesia. But further, the writer has obtained pieces of ore from this vein which were "grown to" dolomite in such a way that it was impossible to say where the hæmatite ended and the dolomite began. Let us now pass to a consideration of the origin of

THE IRON ORES OF THE SECONDARY ROCKS.

The remarks to be made under this head are mainly a reprint of part of the writer's paper on "The Iron Ores of the English Secondary Rocks."

Although all the deposits that have been described as occurring in these rocks are, at their outcrops, more or less hydrated peroxides, yet there is scarcely room for doubt that originally they existed as carbonates, and that they have been altered by the action of oxygenated water in accordance with the reaction indicated by the following chemical formula:—

$$4FeCO_3 + O_2 + 3H_2O = Fe_4H_6O_9 + 4Co_2.$$

In other words, the carbonate of iron has been decomposed, carbonic acid given off, and oxygen and water taken up. One of the results of this reaction is a loss of volume of about 18 per cent. As, however, the ore contains a considerable percentage of impurities which would be unaffected by the above reaction, the loss of volume would not be so great as just stated. For the purpose of illustration, let it be assumed that the constitution of the unaltered ore was as follows:—

	Percentage Weight.
Carbonate of iron	66
Silica, alumina, lime, etc.	34
	100

The diminution of volume resulting from the alteration of this ore, in accordance with the above formula, would be about 12 per cent. Thus an explanation of the open joints and the increased porosity of the ore at the outcrop is obtained, and it is also seen why the ore is more altered and less compact as it is more accessible to atmospheric water, and conversely, why it is more compact and less altered as its protection from the action of such water increases, as set forth in the detailed descriptions of the deposits of Mid-Lincolnshire and Northamptonshire.

The unequal *distribution* of iron in the altered part of the

bed—that is, in the alternating bands of yellow and brown ore—is a problem of more difficulty, but it is clearly connected with the jointing, and, therefore, most probably with the circulation of atmospheric waters. From the analyses given of the different kinds of ore occurring in the deposit at the base of the inferior oolite in Mid-Lincolnshire, and which may be considered as typical of the several varieties of ore in most of the deposits, it appears that the yellow ore contains less and the brown ore more iron than the green or grey ore (whence they were both derived). The iron in the latter descriptions of ore is, however, distributed much more evenly throughout the mass, or perhaps it is more accurate to say that the variations are not nearly so great or so sudden as in the weathered portion of the bed. The existence of the green and grey cores, and their increasing size as "day" is left, shows that the alteration has been gradual, whilst such sections as those exhibited in the mine at Lincoln prove that it has taken place, first along the lines of jointing, the ore adjoining the main joints first showing evidence of the change, and afterwards that traversed by the smaller divisional planes. There being, as already described, three sets of joints—the bed joints and two sets of vertical joints nearly at right angles to one another—the ore is split up into cubes and parallelopipedons of various sizes, so that oxygenated water acting along these joints would, in the course of time, produce the irregular cuboidal and spheroidal structure described in the various parts of Chapter VII., Part II.

The alternation of the yellow and brown ore seems to be due to the intermittent character of the alteration, the brown bands denoting the limits of the various stages in the change. This supposition is supported by the fact that one of these brown bands is always found surrounding the green and grey cores, the only part of the original bed that now remains. From the manner in which the proportion of brown ore to yellow decreases as the distance from the outcrop increases, it is not improbable that the first formed peroxide may, by the alternate action of organic matter and oxygenated water, have

undergone repeated partial dissolutions and precipitations, by which the relative quantity of brown ore has been increased. The yellow ore being much more porous than the brown ore, and, therefore, much more easily traversed by circulating waters, it is natural to suppose that any subsequent action on the peroxide after its first formation would be in this yellow ore, and that as, in the case of its first precipitation, a brown border was produced, so it is probable that at each succeeding precipitation this border would be increased, until ultimately the yellow ore would disappear entirely, having all been converted into brown ore.

The magnetic character of the deposit at Rosedale West seems to be due to the partial peroxidation of the carbonate in the oolitic grains. The "seam of the district," overlying the magnetic deposit, appears also to have been similarly altered, but to a less extent.

Behind these questions there is a further one which naturally suggests itself, and that is, How did the carbonate originate? Most of the writers, if not all, who have entered upon this part of the subject are agreed that the ores were not formed contemporaneously with the rocks in which they occur, but afterwards. There is, however, less agreement among them as to the *manner* in which the ores were deposited. A few quotations will make this clear. Mr. Sorby,[1] writing in 1856 on the Cleveland main seam, said: "An examination of the composition of the shells of the seam shows that whilst some of them still retain their original composition—almost entirely carbonate of lime—others have changed into carbonate of iron."

"The microscopical investigation of a thin transparent section of the stones shows far more clearly that the minute fragments of shell have been similarly altered, the replacing carbonate of iron extending as yellowish, obtuse, rhombic crystals from the outside to a variable distance inwards, often leaving the centre in its original condition as clear colourless

[1] *Proceedings of the Geological and Polytechnic Society, West Riding Yorkshire*, 1856-7.

carbonate of lime, though in many instances the whole is changed. The oolitic grains, likewise, have such peculiarity as indicates that they were altered after deposition."

"The peculiarities in microscopical structure, already described, prove that the same change has occurred in the case of a large proportion of the constituents of the Cleveland stone."

"Independent, then, of the silica and alumina resulting from the clay so commonly found in limestone, and the phosphate of iron, the general composition of the ironstone is very similar to that of the altered shell, so that as far as the chemical composition is concerned, the same circumstances that must have altered the shell may have changed an ordinary lime into such a rock in the manner indicated by the microscopical structure to have really been the case."

Mr. S. Sharpe,[1] speaking of the Northamptonshire ore in 1870, says: "The numerous living organisms, of which these fossils (many of them, as it were, cast in iron) are enduring monuments, could not possibly have existed in waters charged with iron to the degree apparently indicated by the present condition of the rock. The iron must have been introduced after the deposition of the sedimentary material, by infiltration doubtless, but whence derived is a problem yet, I think, to be solved."

Mr. J. W. Judd,[2] writing on "The Mode of Formation of the Northamptonshire Iron Ore," says: "The abundance of molluscan remains in some of the beds of ironstone, indicating, as we have seen, that the animals lived and died upon the spot, precludes the idea that the medium in which the beds were deposited could have been a strong solution of iron."

"The fact that many of the shells in the unweathered rock are more or less completely converted into carbonate of iron is, as Mr. Sorby has shown in the case of the Cleveland ore, a strong proof of the metamorphic character of the rock."

"It would be easy to show, were it necessary, from the immense amount of denudation which has taken place in the

[1] *Quarterly Journal of the Geological Society*, vol. xxvi., p. 13.

[2] "Geology of Rutland," *Survey Memoir*.

district, that the beds of iron ore now exposed to our observation must have been long buried at great depths in the earth. During this period, one of almost inconceivable duration, water containing carbonate of iron would appear to have constantly penetrated the porous sandy rock, and thus gradually effected its metamorphosis into an iron ore. The action of this water would be twofold. In the first place, it would deposit around the grains of sand and in all the interstices of the rock the dissolved carbonate of iron; and in the second place, acting under the favourable conditions of great pressure and high temperature, it would dissolve a portion of the silica and other ingredients of the rocks. Of the matter thus dissolved one portion appears to have been re-deposited in new combinations, and with the carbonate of iron to have formed the oolitic concretions, while the remainder was probably carried away in solution."

Mr. W. H. Hudleston,[1] in reporting an excursion of the Geologists' Association to Northamptonshire, suggests that the ore there has been formed by the replacement of limestone. He says: "It must be borne in mind that most, if not all, of these oolitic ironstones, either in Yorkshire or Northamptonshire, are overlain by porous sandy beds, which frequently contain considerable traces of carbonaceous matter. This probably is but a vestige of what once existed in the peaty beds accompanying 'estuarine' conditions. Layer after layer of micaceous sands, rich in iron, have been permeated by organic acids, the products of the decomposition of these vegetable masses, which, attacking the mica and any such basic minerals which might be present, removed their more soluble constituents, and thus, by perpetually exhausting the sands, left those bleached and partly coherent masses which so often overlie the ironstone beds. This is probably one source of the iron, as the solution originating in the manner described above, and the ultimate decomposition of which would most probably result in the formation of carbonates, might possibly, in the presence of an

[1] *Proceedings of the Geologists' Association*, No. IV.

excess of carbonic acid, decompose and replace any lime carbonates they might meet with in their descent. The presence of an impervious bed of clay at the base of such rocks would materially facilitate the operation by keeping the original oolite in a sort of bath containing a solution of the replacing salt."

So far as the Northampton ore and the Cleveland main seam are concerned, which appear to be the only deposits in the secondary rocks that have been considered from this point of view, there is a consensus of opinion that they were not formed contemporaneously with the enclosing rocks, but subsequently. With that opinion the writer agrees entirely, and would extend it to all the other deposits of the secondary rocks referred to here. It is altogether incredible that the marine organisms, whose remains occur more or less abundantly in most of these deposits, could have lived in water holding in solution such a quantity of iron as would be necessary to convert their shells into a carbonate of that metal. Besides, as will be shown in the sequel, it is quite unnecessary to assume anything so much opposed to experience.

Reverting to the preceding quotations, it is found that Mr. Sharpe does not enter into particulars as to the manner in which he conceives the Northamptonshire deposits to have originated. Mr. Judd, however, does. He assumes the bed to have consisted originally of sand, and that the carbonate of iron was deposited partly in the interstices of the sand and partly in place of some of it. Mr. Judd considers that, under certain conditions of heat and pressure, some of the sand might have been dissolved. The improbability of such a mode of origin is, in the writer's estimation, something enormous. He cannot conceive of silica being dissolved by any carbonated solution of iron which did not also remove every vestige of lime in the inorganic remains. As a matter of fact, however, many of the shells met with in the ore are in their normal limy condition. Mr. Judd's explanation, moreover, does not afford any clue to the oolitic structure of the ore, nor to the fact of its containing alumina, lime, and other ordinary rock-forming

minerals, in proportions which do not vary greatly in different areas, and which do not seem to be influenced in any way by the varying nature of the overlying rocks; for instance, the proportions of silica, alumina, lime, and magnesia do not differ materially in the ores of Northampton and Mid-Lincoln, notwithstanding that the former is overlain principally by sand, whilst the latter is covered by a thick mass of limestone. In North Yorkshire the same bed is overlain by an enormous thickness of sandstones and shales, yet the proportions of alumina, etc., in the ore are almost the same as at Northampton; and the statement is not sensibly affected if the comparison is extended to the ores of the middle lias, which are everywhere overlain by clay. Mr. Judd's explanation is therefore insufficient.

The suggestions of Mr. Sorby and Mr. Hudleston as to the origin of the Cleveland and Northamptonshire ore respectively, are that they were produced by the replacement of an ordinary limestone. Mr. Hudleston also considers that the ironstone of the dogger series of Yorkshire originated in this way.[1] Both these geologists found their conclusions on the fact that the ores contain shells which are partly or wholly converted into carbonate of iron.

This explanation, which commends itself to the writer, was arrived at independently by him, and he would extend it to each of the deposits mentioned as occurring in the secondary rocks. His reasons for so doing are as follows: In the first place, there is such a great similarity in the character of the different deposits, that, *à priori*, it is extremely probable they all originated in the same way, and, as will be hereafter pointed out, at least one peculiar feature is common to them all. Let it be assumed that originally the ore beds consisted of an ordinary oolitic limestone, the composition of which was similar to that of some of the lower beds of the Lincolnshire limestone, an analysis of one of which, as it occurs at Lincoln, is given opposite :—

[1] *Proceedings of the Geologists' Association*, No. IV.

Combined water	4·87
Peroxide of iron	8·46
Oxides of alumina and magnesia	2·04
Lime	42·18
Magnesia	·58
Carbonic acid	30·96
Phosphoric do.	·35
Sulphuric do.	trace
Insoluble silicious matter	10·56
	100·00

As this limestone was almost resting on the ore, it may, to a small extent, have been subjected to the same metamorphic action as is assumed in the case of the latter, so that to arrive at its original composition the peroxide of iron and part of the combined water should be struck out from the above analysis, and the lime increased. There would then be a stone consisting mainly of carbonate of lime, but containing also about 10·56 per cent. of silica, 2·04 of alumina, and ·58 of magnesia, with a small quantity of phosphoric acid and a trace of sulphuric acid. The percentages of silica and alumina in this stone, it will be seen, on reference to the analysis previously given, are less than they are in the Mid-Lincolnshire ore; but this is only what might be expected from the decreasing proportion of these materials in the ore itself, from the bottom upwards, as shown below :—

	Silica.	Alumina.
Top-block of ore bed	13·05 ...	3·08
Bottom " "	16·73 ...	3·72

This upward decrease of silicious and aluminous materials and corresponding increase of calcareous matter is surely to be expected in a bed occupying the position of the Mid-Lincoln iron ore, which forms, as it were, a transitional stage between the upper lias clay and the Lincolnshire limestone.

Now, as already pointed out, all the ores that have been described in Chapter VII., Part II., occupy such a position, with reference to masses of clay, that the limestones which are assumed to have preceded the ore, would, in all probability, be more silicious and aluminous than the stone of which the

analysis is given above, and therefore, so far as these materials were concerned, it would correspond more closely with the quantities actually existing in the ores.

The replacement of carbonate of lime by carbonate of iron is expressed by the following formula :—

$$CaCo_3 + FeC_2O_5 = FeCo_3 + CaC_2O_5$$

One of the results of this reaction is a diminution of volume equal to about 18 per cent.; that is to say, the precipitated carbonate of iron occupies only 82 per cent. of the volume of the limestone which it replaces. It is possible, however, that the carbonate of iron may occupy as much space as the limestone which it replaced, but if so, it must be more porous by 18 per cent. In the case of an ore containing, say, 66 per cent. of carbonate of iron, the porosity would only be increased 12 per cent. Thus an explanation is obtained of the increased porosity of the bluish and greenish carbonate of iron occurring in the ore beds, as compared with ordinary oolitic limestone. This increase is partly shown in the following examples, which in No. 1 give the relative porosities of a piece of limestome overlying the Mid-Lincoln ore, and of one of the greenish nodules in the ore bed there. No. 2 is of a piece of limestone underlying the ore at Holwell, and of one of the green cores in the ore at the same place.

	Porosities. Percentage of Volume.	
	No. 1.	No. 2.
Limestone	11·5 ...	8·5
Green nodule	20·0 ...	17·0

These examples do not show so great a difference in the porosities as was stated above, but that is easily accounted for when it is borne in mind that limestones, like other bodies, vary in their porosities, and that those tested were not from the same horizon as the ores, but as near thereto as they could be obtained.

The increased porosity of the ores in their carbonated condition is a feature of all the deposits, except that at Seend,

which, so far as the writer knows, contains iron only as a hydrated peroxide. It is, however, extremely probable that the ore in that deposit existed originally as a carbonate. The sand and pebbles associated with the ore, and which gave the deposit an entirely different character from any of the others, demand special notice. It is quite impossible that this bed could have existed originally as an ordinary limestone, nor is such a supposition necessary, but, just as a considerable quantity of lime is found cementing together the silicious grains of the sandstone blocks which occur amid the coarse sand underlying the ore at Claxby, so it is quite possible that at Seend, originally, the sand and pebbles had a limy matrix. A solution of carbonate of iron coming into contact with this lime would remove it, and leave carbonate of iron in its place, which, by the subsequent action of oxygenated water, would be converted into hydrated peroxide, as is now seen.

Referring to the consideration of the other deposits, it will be seen that by the action of a carbonated solution of iron on an oolitic limestone, containing certain proportions of silica, alumina, and magnesia, an explanation is obtained of the following facts :—

1. The partial, and in some cases the total conversion of the shells into carbonate of iron. This is a natural result of the process of replacement, some shells being more difficult to act upon than others, whilst they all offer more resistance to an acid solution than ordinary limestone.

2. The occurrence of thin beds of limestone in the ore at Frodingham, and of irregular pieces of the same stone in the deposits at Caythorpe and Holwell, all of which graduate into the ore, point out clearly that these beds of ore were formed by the replacement of limestone. The occurrence of limestone also at the bottom of each of these deposits, and its irregular junction with the ore, is further evidence in the same direction, as is also the variable quantity of lime existing in the ferruginous parts of many of the deposits. Take, for example, the ore at Wellingborough, which in four cases gave the following relative quantities of lime and iron :—

	Metallic Iron per cent.	Lime per cent.
No. 1	53·20	·41
" 2	37·00	7·13
" 3	35·37	11·76
" 4	24·09	25·68

The inverse proportion of the lime to the metallic iron which is seen in these particulars is frequently found in the Northampton ore, and in other deposits as well. Below is an illustration of it, from Hutton old mine in the Cleveland main seam :—

	Metallic Iron per cent.	Lime per cent.
No. 1	34·75	3·80
" 2	28·84	4·20
" 3	27·45	7·39

In making a comparison of this kind the ores must be taken within a small area, otherwise the results are liable to modification from the variation of the silica or alumina; for although, as a rule, these minerals are more constant than the lime, yet they vary considerably at times, as will be seen on reference to the analyses previously given in Chapter VII., Part II., so that it is quite possible (if the ores compared were from a large area) to have a small metallic yield with a small percentage of lime, simply because the silica or alumina, or both, may be unusually high.

3. Another fact strongly suggestive of replacement is that the beds in the different ferruginous horizons frequently assume the character of ordinary limestones. In illustration of this remark reference may be made to the fact that the marlstone rock-bed, which is a workable ore of iron in part of Leicestershire and Oxfordshire, occurs throughout most of the intervening area, and in the south-west of Oxfordshire as a limestone.

4. The oolitic character of the ironstones, as well as the presence in them of variable proportions of silica, alumina, etc., are a direct result of the replacement of an oolitic limestone containing varying quantities of clay.

5. The higher metallic yield of the magnetic ore of

Rosedale means simply that the preceding limestone was purer.

One further question remains, and that is the source of the iron. Mr. Hudleston has suggested, in the case of the Northampton ore, that it came from the overlying sands; he also suggests that the ore of the dogger series of Yorkshire originated from a solution of iron formed in the sandstones and shales of the lower estuarine series which overlie the ore bed. The difficulty of accepting these suggestions is, that the ore of Mid-Lincolnshire, which is on the same horizon as those of Northampton and Yorkshire, and is similar to them in all other respects, yet differs from them in this, that it is overlain by limestone.

The close connection of all these deposits with large masses of clay has suggested to the writer that the source of the iron may have been in these clays. The Jurassic rocks rest almost throughout their entire course, from North Yorkshire to South Dorsetshire, on the red irony strata of the Permian and Trias; and there is little doubt that the denudation of the latter rocks contributed largely to the formation of the former. On this point the writer would call attention to the large amount of magnesia in both the liassic and oolitic ores of Cleveland, which is difficult to account for, unless it be supposed that the limestones which preceded these ores were mixed with materials derived from the large area of magnesian limestone to the north-west. However that may be, it is almost certain that the clayey and sandy beds of the lias and oolite were derived in a great measure from the red rocks to the north-west. Hence the large quantity of iron in them. On next page are given analyses of the upper and lower lias clays, as well as of the Kimmeridge clay, from which it will be seen that they all contain a large quantity of iron.

A solution of carbonic acid would dissolve the protoxide of iron in the clays, and this solution, in its circulating movements through the rocks, would be precipitated by the limestones, which, it is supposed, occurred at the top and bottom of the upper lias clay, or, as in the case of Frodingham, amid

Constituents.	Lower Lias Clay overlying Cleveland ore.	Upper Lias Shale overlying Frodingham ore.	Kimmeridge Clay overlying Westbury ore.
Silica	51·70	48·83	51·24
Alumina	18·52	20·41	18·76
Lime	1·76	4·18	4·56
Magnesia	1·90	2·01	1·56
Potash	·17	2·48	·86
Soda	·16	·86	·74
Protoxide of iron	9·68	6·14	4·32
Peroxide " "	—	—	2·88
Carbonic acid	3·16	2·84	1·99
Sulphur	1·96	·78	1·68
Water and organic matter	10·79	11·47	11·40
Total	99·80	100·00	99·99

the clays of the lower lias. The alternation of the deposits previously pointed out, if it should be real, may have resulted from the different directions taken by the underground currents.

Although the direct source of the iron may have been the clay contiguous to the deposits, yet the writer is of opinion that its original source was volcanic, that, assuming it to have been derived from the clays as suggested, it came originally to the surface at the time the hæmatite deposits of Cumberland and Lancashire were formed, and that, in the first instance, it was deposited along with the sands and shales of the Permian and Trias. By denudation, these latter rocks were subsequently in part removed, and re-deposited in the sedimentary strata of the secondaries. As just seen, these sediments contain abundance of iron, but it is scattered through such an enormous mass of earthy material as to be utterly valueless for metallurgical purposes. By subsequent chemical action, however, this iron, or some of it, would assume a mobile condition, and circulate with the underground waters, from which it would be precipitated, in a concentrated form, by the limestones, which, it is supposed, preceded the ore beds.

It is possible, however, that these deposits may have originated in Tertiary times from an abnormal circulation of

ferruginous waters. The middle part of that period, we know, was marked by volcanic activity, and it may have been, for that reason, just as great an Iron Age as the Permian.

This somewhat lengthy discussion of the origin of the West Cumberland and Furness hæmatites, and the limonites and siderites of the Secondary rocks, will enable us to deal briefly with the remaining ores described in Part II.

Limonites of South Wales and the Forest of Dean.

Sir H. T. de la Beche, writing on the formation of the rocks of South Wales and South-Western England,[1] says:—"The Dean Forest section presents us with an interesting local accumulation of peroxide of iron intermingled with the calcareous deposits of the time, so that we should regard the iron as having constituted as much a portion of the rocks, in a particular part of the general series, as any other marked beds. It has long been extensively worked, so that its mode of occurrence is well understood. It ranges in variable quantities but always in its relative geological position, cropping out round the basin-formed mass into which the beds of Dean Forest have been forced. Though hæmatite iron ore is known elsewhere among the carboniferous rocks of South-Western England and South Wales, in some localities having been raised in large quantities, it has hitherto, in them, been only detected in veins, with the exception, perhaps, of the hæmatite ore raised from the carboniferous limestone for the Pentyrch ironworks, north of Cardiff, the position of which is somewhat equivocal. Although in endeavouring to account for the position of the iron ore in the carboniferous limestone of Dean Forest, we may, from existing knowledge, be led to suppose that it was formed in the sea, amid the marine accumulations with which it is associated, so that it may not have been a bog iron ore of that geological period, still its dispersion at the same time over so wide an area would induce us to infer that the peroxide was thrown down from water in which the iron had

[1] *Memoirs of the Geological Survey*, 1846.

previously been in some soluble form spread over the space required."

Dr. J. W. Watson,[1] in a paper on the ironstone formation of the Forest of Dean, says: "The 'Mine Measures' may have been the result of a rapidly accumulated calcareous silt, afterwards so altered by contraction and upheaval, as to have had all evidence of lamination and bedding obliterated, and from being fissured during elevatory movements may have become gradually cavernous by the mechanical and solvent powers of water. Into these fissures and hollows, water, saturated with carbonic acid, and holding proto-carbonate of iron in solution, may have deposited the iron by a gradual escape of part of the carbonic acid, in the same way as in the case of calcareous 'sinter,' when, by the admission of oxygen, it would soon become peroxidised."

A careful consideration of the South Wales deposits and of the manner in which the "hanging wall" is formed by clay or shale, leads to the unavoidable conclusion that those deposits originated by a process of substitution, like the deposits of Cumberland and Lancashire. It is simply impossible for them to have been formed in cavernous receptacles. The clay or shale forming the hanging wall could not have stood, unsupported, even for a moment.

The Dean Forest deposits most probably originated in the same way, though the evidence in their case is not so strong.

Whether the ores were deposited as limonites, or as siderites, from which they have been altered, it is impossible to say with certainty, but the probabilities favour the former.

The powdery and fine gravelly character of the "smith ore" may have originated from the dissolution of limestone, which originally bound together the innumerable fine particles and small pieces of ore in a manner similar to that in which the limonite of the "grey ore" is held together by dolomite.

[1] *The Geologist*, 1858.

The Iron Ores of Cornwall, Devon, and West Somerset.

The whole of these ores are doubtless substitutional.

The irregular deposits in the Devonian limestone are easily explained in this manner.

The bedded-veins in the "killas," etc., in all probability were formed by the replacement of thin limestone beds, which were contemporaneous with the associated shales, etc., whilst the veins that cut through the beds, and which are, in the majority of cases, on the lines of dislocations, may have come into existence by a double substitution, as explained in the case of veins in the slaty and granitic rocks of Cumberland.

The limonites in many cases, if not all, have resulted from an alteration of siderite, which, in such cases, was the original ore.

The hæmatites, in all probability, were deposited as such, in the manner already explained when treating of the West Cumberland ores.

The magnetites may have been siderite or hæmatite originally, and have been altered, subsequently, by the same metamorphic process which induced the present character of the accompanying rocks.

The Limonites and Siderites of Alston and Weardale.

There cannot be any doubt that the siderite, which was the original ore here, and from which the limonite was produced by alteration, was formed by a replacement of limestone. The "growing together" of the two minerals, where they are in contact, is alone sufficient to prove this; but the same conclusion is reached when the veins are considered in the light of the arguments against filled fissures, which were adduced in a previous part of this chapter.

The Argillaceous Ironstones of the Carboniferous Rocks.

As to the manner in which these ores originated not much has been written.

Mr. T. Lucas[1] considers "the formation of all varieties of clay ironstone lying in beds is rendered intelligible by the supposition that they were formed in peaty or non-peaty lagoons, on the alluvial flats of the deltas of the carboniferous formations, according to the predominance or absence of carbonaceous matter in the ironstone." He believes the crack-like cavities, so often seen in nodules, "to have been formed under these circumstances by the sun when the stagnant pools dried up, as they exactly resemble those found in the substance of ordinary clay under similar circumstances."

Mr. James Geikie[2] is of opinion that the numerous coal seams point to a recurrence of a land surface, and the gas coals and ironstones to the former existence of numerous wide lakes and lagoons."

"Over the bed of the lake would gather a slimy vegetable mud, which in some places might be highly impregnated with ferruginous matter." In this way he accounts for the blackbands. With regard to clay ironstones, he considers "they are often due to subsequent changes in the strata. The carbonate of iron having been more or less diffused through the silt beds or shales, has segregated in time, so as to form irregular balls or bands. But the extreme regularity of many of the bands would lead me to infer that these, at least, were due rather to deposition than to segregation."

Sir A. Geikie[3] considers these ironstones were "deposited from solution in water in presence of decaying organic matter."

Mr. R. Hunt[4] is of opinion that "the present condition of our coal-measure ironstone formations was the direct result of the process of coal formation, the water in which the coal was formed removing from the surrounding rocks, by virtue of the dissolving power of carbonic acid, the iron which they con-

[1] "Origin of Clay Ironstone," *Quarterly Journal of the Geological Society*, vol. xxix., part 3.

[2] "On the Geological Position and Features of the Coal and Ironstone-bearing Strata of the West of Scotland," p. 14.

[3] "Text Book of Geology," first edition, p. 84.

[4] *Quarterly Journal of Science*, vol. v., 1868.

tained. This, if retained within the coal basin, gradually produced the argillaceous carbonates of iron as we find them; but if the ferruginous waters passed away from the influence of the dissolved vegetable matter their oxidation ensued, and hence the deposits of hæmatite in ponds and fissures, as we see them near Ulverston."

The writer cannot agree with any of these explanations. From the large amount of lime existing in some of the poorer varieties of ore he is disposed to look upon them as partial or complete substitutions after limestone. The conversion of the limy substance of the fossil shells into siderite also points to the same conclusion, whilst the crack-like cavities in the nodules, and their absence from the beds, can be much more satisfactorily accounted for on the hypothesis of replacement, than in any other way. If these cavities are due to the action of the sun, as suggested by Mr. Lucas, why do we not find them in the beds and nodules alike? And further, why are they only found in the interior of the nodules, and not extending to the outside?

Let us assume that these nodules and beds were originally limestones, more or less pure. This assumption is quite warranted, for the occurrence of thin limestones as the roofs of coal seams is not an uncommon feature in similar strata. Take, for example, the lower carboniferous rocks of Northumberland. In the case of the nodules it will probably be admitted that the limestone would become purer towards the centre, that is as the distance from the surrounding shale increased. When, therefore, the limestone was replaced by carbonate of iron, the outer portion of the nodule, being more mixed with shale, would not be so pure as the centre, and that is what we actually find. But further, the contraction of volume, due to the replacement of limestone by siderite, would increase with the purity of the original limestone,—that is to say, would increase inwards,—and that is why we find these cavities widest in the centre of the nodules.

The absence of cavities in the beds is probably due to the compressive action of the superincumbent strata at the time

the conversion was effected. This idea is supported by the flattening of the shells in the beds, but in the case of the nodules compression could only affect small ones, or the outer surface of those that were larger, because the shale between the nodules on any given layer would bear up, in a great measure, the overlying rocks, and so prevent any weight coming on to the nodules except just at first, the conversion, of course, taking place from the outside inwards.

The writer is further inclined to the replacement conclusion by two other considerations: first, the absence of direct evidence that suchlike deposits can be formed otherwise; second, the contradiction of all experience involved in the assumption that organisms, such as those frequently included in these ores, could ever have lived in water so highly charged with ferruginous matter, as must have been the case if the ores be contemporaneous deposits.

The erroneous notion that the vegetable matter of coal grew on the spot receives a rude shock when it is attempted to explain in that way the thin layers of coal found in blackband ironstones.

The Iron Ores of Antrim.

Lithomarge and Bole. The manner in which these beds have been produced seems to be rendered perfectly clear by the presence in them of the concretionary nodules already noticed. The gradation from bole to basalt, and from lithomarge to basalt, as seen in the nodules of the respective beds, indicates very clearly that both bole and lithomarge are the result of metamorphic action on basalt. The appearance presented by these nodules cannot possibly be explained on any other assumption; but whether the rock from which the two beds were produced was exactly alike in chemical constitution, as well as like that of the basalt now above and below them, it is impossible to say. The probability is, that the beds of rocks from which the bole and lithomarge were produced, differed in their chemical constituents; if not, and it is assumed that they were both subjected to the same metamorphic action,

then the lithomarge and bole must represent two different stages of the metamorphic process. But if bole were metamorphosed lithomarge, that is, if it had undergone a higher degree of metamorphism than lithomarge, there would be found, in the concretionary nodules of the bole, a transition from basalt to lithomarge, in the first place, and then from lithomarge to bole; in other words, between the bole and basalt forming the centre of the nodules, there would be found a layer of lithomarge, which is not the case. Then again, if lithomarge were altered bole, there would be found, in the concretions of the lithomarge bed, a layer of bole immediately round the basaltic kernels, which does not appear. These facts go to show, either that the bole has been produced from a bed of basalt chemically different from that which, by alteration, has resulted in lithomarge, or that the metamorphic process was not alike in the two cases. The analyses previously given show that basalt differs in its composition from lithomarge and bole, mainly, in the proportions of the constituent materials, especially the silica and alumina, as shown by the percentage weights hereunder:—

	Silica.	Alumina.	Lime.	Magnesia.
Basalt ...	46·71	19·86	4·15	4·00
Bole ...	6·4	35·15	·39	·59
Lithomarge ...	40·22	28·46	·43	1·47

The ratio of silica to alumina in these three rocks is:—

Basalt	1 to	·42
Bole	1 „	5·49
Lithomarge	1 „	·7

It may be, therefore—indeed, it is very probable—that the difference between lithomarge and bole has resulted from the removal of a larger proportion of silica from the original rock in one case than in the other.

A fact which may throw some light on the mode of metamorphism may be observed in connection with the bed of clay lying between the pisolitic ore bed and the overlying basalt. This clay is most probably also metamorphosed basalt,

for there is a most gradual laminated passage from the hard basalt to soft clay. Whenever this clay bed crops out to "day" it appears to thicken. This would seem to indicate that whatever was the metamorphic action which produced the clay it acted most powerfully near the surface.

Pisolitic Ore. This bed has been accounted for in various ways. Some writers have supposed it to be of igneous origin, others consider it to be metamorphosed bole,[1] whilst Professor Hull[2] and Mr. Du Noyer[3] are of opinion that it had an aqueous origin. The fact previously referred to, that fossil wood and other plant remains have been found in the bed, seems to favour the last idea, although the mode of deposition advocated by those who hold it differs greatly, Mr. Du Noyer supporting a sedimentary, whilst Professor Hull suggests a chemical, process. In either manner, however, it is difficult to account for the proportions of the non-metallic minerals associated with the ore. They are not those of sedimentary matter derived from ordinary silicious and aluminous rocks. In such sediments silica largely preponderates. If we take the average of the analyses of pisolitic ore, given in Part II., we find the non-metallic minerals to have the following proportions:—

Silica	6·46
Alumina	9·53
Lime	·92
Magnesia	·3

The ratio of the silica to the alumina is 1 to 1·47. When we compare this with the ratios of these minerals in bole and lithomarge, as given above, there is a strong disposition to believe that the pisolitic ore is also a product of metamorphism.

[1] Tate and Holden, "On the Iron Ores associated with the Basalts of the North-East of Ireland," *Quarterly Journal of the Geological Society*, vol. xxvi., part 2, 1870.

[2] *British Association Report* (Belfast 1874), p. 70.

[3] "On the Geology of Island Magee," *Natural History and Philosophical Society of Belfast*, 1868.

In no other way can the writer account for the low percentage of silica as compared with the alumina.

The plant remains have not been found in many localities, and may have been accumulated in small isolated sheets of water in the intervals between successive lava-flows. These plant remains are the only impediment in the way of an unreserved acceptance of the suggestion that the pisolitic ore had a metamorphic origin ; but, it may be thought, the suggestion just made meets the difficulty in a satisfactory manner.

It will probably be asked, if this ore is the result of metamorphic action, why does the same sort of pisolitic ore not accompany the other bole-beds ? They were all alike overlaid by a bed of basalt, which, according to the holders of this view, was instrumental in producing the pisolitic character of the ore. In explanation of this, two suggestions may be made: (1) The mineral composition of the bed preceding the pisolitic ore might be different from that of the beds overlying the other boles; or (2) the physical condition of the basalt over the several bole-beds might be unlike at the time of formation. In this connection it may be mentioned that the basalt resting on the pisolitic ore is columnar; over the other boles it is either massive or concretionary.

That silica, alumina, lime, magnesia, etc., can be removed from rocks, by underground waters, we know from the frequent occurrence of these minerals in springs. It is also a suggestive fact that alumina is much less frequently present in these waters than silica.

It is very likely, however, that during the volcanic times which followed the deposition of the beds preceding these ores waters might be put into circulation through the rocks which had a much more powerfully solvent action on them than ordinary spring water.

The magnetic character of some of the ore, as well as its spheroidal character, is probably due to the influence of the overlying basalt whilst in a molten condition.

The Iron Ores of Spain.

Vizcayan Deposits. There cannot be any doubt that these deposits originated by a process of replacement. It will be sufficient to remember the San Miguel quarry, where the ore is covered up by shale—a state of things which could not possibly have happened if the ore had been deposited in pre-existing caverns. This shale would clearly have fallen away, if left unsupported, whilst the production of the ore contemporaneously with the limestone is altogether out of the question. The original ore was doubtless formed as a carbonate which has been altered into rubio, campanil, and vena, through the action of the air and oxygenated waters.

The *modus operandi* of this change is partly shown by the kernels. Why the process of alteration should have resulted in the formation of campanil, or of campanil and vena at one place, and of rubio, or rubio and vena at another, is not quite so clear; but the writer is disposed to think that these variations are simply consequences of the different conditions under which the change has been effected; campanil being the result where the change was carried out under a shale or limestone cover, as at Triano, whilst rubio was produced wherever air and water had free access to the original spathic ore, through its being exposed by denudation. A very much larger area of campanil may have existed once at Triano than that worked, and have been subsequently altered to rubio; for we have it proved that such a change can take place by the fact already mentioned, that campanil has been found as the nuclei of rubio. Vena is clearly the last stage in the process of evolution.

The source of the iron which produced the original carbonate may have been in the shales overlying the limestone. These rocks, like most shales, contain a considerable quantity of iron; but there is a difficulty in this supposition. Seeing that the shales once overlaid the limestone at every point, how do we account for the localisation of the deposits in certain

places only, with large areas of barren limestone between them? That may be owing to the presence of faults, in the particular localities where ore was formed, for, as a matter of fact, these dislocations are found near most, if not all the deposits. In this way the difficulty is surmounted in a fairly satisfactory manner, for the circulation of underground waters would be much more active along these lines of fracture than elsewhere. It is, however, possible that the iron might have been conveyed to its present resting place by underground waters during the period of volcanic activity, which resulted in the elevation of the Cantabrian range.

Malaga Deposits. The origin of the magnetites of this area is much more difficult to account for than that of the Vizcayan deposits, but the writer is convinced that the explanation which he has given of the origin of the hæmatites in the Skiddaw slates and the volcanic rocks of Borrowdale will also account for the ores in the archæan rocks here, but without a double replacement. If we assume that the magnetites were preceded by dolomite it is quite easy to understand how these ores, like those of Vizcaya, could have been produced by replacement, and the writer is satisfied that they originated in that way. The assumption of the pre-existence of lenticular masses of dolomite where the ore now occurs is rendered highly probable when we remember that even now similar masses alternate with the silicious and aluminous rocks adjoining the ore deposits, and the idea is still further strengthened by the occurrence of pieces of dolomite, actually, in places, forming a wall to the ore. In the Estapona deposits we have as clear a case of replacement as in the hæmatite deposits of Cumberland. The old idea of filled caverns and fissures is altogether untenable, and it is not a little surprising that in a text-book like Geikie's it should still be propagated. The veriest tyro in mining, when it is brought under his notice, will at once see an insuperable objection to such an idea, in the impossibility of keeping such large spaces open whilst they were being filled, especially where there are shale roofs or soft slaty walls to the deposits.

What the original form of the magnetites was it is impossible to say; it may have been either siderite or hæmatite. Its magnetic character is, in all probability, due to the same metamorphic action that has operated on the enclosing rocks and produced such changes in them.

PART IV.

SEARCHING FOR AND WORKING IRON ORE.

CHAPTER I.

INTRODUCTORY.

LITERATURE.

IN addition to the works already mentioned in Part II., some of which contain incidental references to the modes of working, the following may be named:—

1. "Ironstone Mining in Cleveland," by A. L. Steavenson. *Journal Iron and Steel Institute*, 1874.
2. "Searching for and Working Hæmatite Deposits," by J. D. Kendall. *Colliery Guardian*, 1876.
3. "The Iron-Ore District of Bilbao," by W. Gill. *Journal Iron and Steel Institute*, 1882.
4. "The Bilbao Iron-Ore District," by B. J. Forrest. *Transactions North of England Institute of Mining and Mechanical Engineers*, vol. xxxiii.
5. "Vizcayan Mining Industry," by Jeremiah Head. *Proceedings of the Cleveland Institute of Engineers*, 1888.

Having examined our subject from the standpoint of the geologist, let us now look at it from that of the mining engineer. In doing so, however, we must take the geologist with us, at least whilst we are searching for ore. A mining engineer who is not a geologist, is like a metallurgist who is not a chemist—simply a one-legged man. It is, perhaps, somewhat late in the day now to urge the value to the mining engineer of a knowledge of geology, but it is more than likely

that a generation will have to pass away before the present type of self-styled practical man entirely disappears. We still have with us a race of men who are deeply enamoured of the rule of thumb, and who cannot conceive of anything being practical which is outside the operations of their one-sided experience. Such men treat the opinions of the geologist with scant courtesy, and, by way of exhibiting their contempt for his knowledge, dub him a theorist. In the uncomplimentary sense they erroneously attach to that word there are no greater theorists in existence than these so-called practical men. Whilst they are engaged in work to which they have been educated, they may be safely trusted, but the minute they step outside such operations they are as much at a loss as any other set of men who undertake duties in which they have had no training.

The work of the geologist is just as practical as that of the miner, although much of it does not concern the mining engineer. In that which does however there are, no doubt, among the students of geology, as among those of the other sciences, men who do not pay that regard to experience which safe action demands; but that, unfortunately, is a defect which exists very widely. Even among those who follow the comparatively simple operations of the miner, we find it most glaringly exemplified. If this latter class of men always directed their actions in the courses dictated by experience, the list of accidents in mines would be very materially reduced. There would not then be that need for inspection which some of them wish the public to believe exists at present. After nearly thirty years' experience in mines of almost every kind, the author has not the least hesitation in saying that, if miners were but half as careful of their lives as most managers are to protect them from accident, we should hear of very few of those distressing occurrences that every now and again bring misery, it may be despair, to many a struggling household.

But to return to the question of geology as applied to mining. The geological knowledge which is advocated by

the author is not such as is obtained from books,—although that may be of the greatest assistance as an auxiliary—but rather that which comes from practical work in the field, the quarry, and the mine, from geological mapping and the correlation of sections, to determine the order of succession. In the acquirement of this knowledge a man becomes familiar with the nature of mineral deposits and the horizons on which they occur, and he is therefore able to direct his explorations with the greatest chance of success, and at the least cost to the adventurer.

CHAPTER II.

SEARCHING FOR IRON ORES.

THE various methods of boring have been so often described, in text-books and elsewhere, that it is unnecessary to speak of them here. For the same reason it would be superfluous to say anything as to the modes of carrying out the various works, such as drifts, shafts, and trenches, usually employed in explorations.

The first essential, in looking for iron ore, is to have as accurate a knowledge of the geological structure of the district to be explored as it is possible in the circumstances to acquire. Without this it becomes mere guess-work, as it used to be in Cumberland and Furness not many years ago. In those days it is known that, in order to fix the position of a borehole, a penny or some other article has been thrown up into the air, and wherever it fell the borehole was put down; and even to-day boreholes are put down, by some of those so-called practical men, in positions that are fixed upon for no other reason than that there has not been a hole there before. Mining is always sufficiently expensive without throwing away money in this absurd manner.

Having determined the structure of the district to be explored, the mode of procedure will depend entirely upon the character of the deposit sought. Iron ore occurs in workable bodies, as veins, beds, and irregular deposits, and there are features peculiar to each of these forms which demand special consideration and treatment. Let us take them in the above order.

Veins.

Such as the hæmatite veins of Cumberland or the magnetite veins of Spain.

If the ore occurs in this form it may be, if the superficial covering is thin, and it usually is in the mountainous districts where frequently veins exist, that much can be done by trenching—that is, cutting across the assumed line of the vein at intervals. Should this be successful in ascertaining the position of the vein, and perhaps also its length and width at the surface, the next thing to be done is to prove its character in depth. For this purpose, it may be necessary to sink a few small shafts on the "hade" of the vein, or to put in one or

Fig. 24.—Section Showing Mode of Proving a Vein.

more drifts at a lower level, and drive at right angles to the course of the vein until that be intersected. This is illustrated by Fig. 24. It sometimes happens that trenching cannot be done satisfactorily, or even at all, owing to the great thickness of the superficial deposits. Then the explorations have to be conducted entirely by drifting. It may be that one or more tiers of drifts are necessary.

Owing to the high angles at which veins usually occur, it is clear that boring, or even sinking, is not so likely to be successful as drifting, although these methods have been employed occasionally, in certain circumstances. The horizontal area of a vein is usually small compared with the surface

which it presents vertically in the direction of its length, and therefore a horizontal exploration, where possible, will be more likely to succeed than one that is vertical.

BEDS.

For the reason just given, boring or sinking is much more likely than drifting to be successful in searching for an ore bed (unless it be very highly tilted), and on that account is more generally employed. If a bed occurs in a hilly country, and the outcrop is visible, or has been proved by trenching, drifting may then be quite as efficient as either boring or sinking in proving the extent of the bed; but if the absolute level of the bed is not known, then vertical explorations must be resorted to. Beds of ore having a thick cover, like that of Cleveland, may be sought either by trenching or boring, supplemented by drifting to prove the extent. Beds near the surface, like that of the lower oolite of Northamptonshire, can be best sought for, and proved, by trenching or sinking.

IRREGULAR DEPOSITS.

The search for these deposits is infinitely more complicated and difficult than that for either beds or veins, and therefore it will be treated more fully. Much, however, that will be said under this head will apply with equal force to explorations for both veins and beds.

As the deposits of Cumberland and Furness are, by common consent, the most difficult to understand of any in Britain, we will illustrate our remarks by reference to those districts. It will be seen in the course of these remarks how indispensable is a knowledge of geology to any one searching for ore in those districts,—although it is only a question of degree,—for such knowledge is always necessary to the explorer. Many of the errors that have been committed by so-called practical men, ignorant of geology, who have been charged with the direction of explorations are most instructive, and some of them will be here pointed out.

It has been shown in Part I. that the deposits in the car-

boniferous rocks of West Cumberland and Furness occur in the thick limestone of the latter district and Millom, and in the seven limestones that are found in the neighbourhood of Whitehaven. It will be clear, therefore, that it would be useless to search for a workable body of ore in the red shales with thin limestones which underlie the thick limestone of Furness, and yet some eighty or a hundred deep boreholes have been put down in those rocks between Dunnerholm and Askam in search of hæmatite, at enormous cost. It may be said, of course, that we are wiser now than we were before those holes were put down, and that it is quite easy to see the mistake to-day. But that is not so. Any one having an accurate knowledge of the geology of the district would have been satisfied after the first bore had gone a few fathoms; for the physical features of the area referred to are altogether unlike those of the district occupied by the thick limestone, and further, the character of the strata is wholly different from that of any other series of rocks in Furness. Admitting that the features of the surface are not always perfectly reliable as to the nature of the underlying rocks, since they may be modified by superficial accumulations, yet to have overcome any doubt on that score would only have needed a few shallow bores, the cost of which would have been trifling compared with that of the large number of deep bores already mentioned. In another part of Furness boreholes have been carried down, through the lower limestone shales, thirty or forty fathoms into the Silurians.

The same error has frequently been committed in the Whitehaven district. A case of the kind is shown in Fig. 25, where a number of bores (many more than are shown in the figure) were put down in the Skiddaw slate, which a knowledge of the geology of the district would have prevented. The nature of the solid rocks, it must be admitted, is, in a great measure, hidden by a covering of sand, gravel, etc., but abundant data had been already obtained by other bores, and by the workings of adjacent mines, to enable any geologist to mark out the Skiddaw slate area.

We will now take a case of a different kind, and one which has only just been completed. Figure 26 is a section of a part of the Whitehaven district where the limestone, the Skiddaw slate, and the Saint Bees sandstone may all be seen on the surface, and their relations accurately determined; yet a borehole was put down in the position shown in the figure, where, it will be readily understood, there was not a possibility of meeting with ore. This hole was put down in the

FIG. 25.—GEOLOGICAL MAP OF PART OF FRIZINGTON DISTRICT.

References—*A* St. Bees Sandstone. *B* Breccia. *C* Millstone Grit. *D* Limestone. *E* Lower Limestone Shale. *F* Skiddaw Slate. *G* Hæmatite.

latter part of the present year (1892), when few people have an excuse for not knowing something of the geology of the district.

In another part of the same district a number of bores were put down through Permian rocks. After passing some depth into the breccia, which in parts is made up almost entirely of blocks of carboniferous limestone, they were stopped in the position indicated by No. 1 borehole in Fig. 27, the person in charge thinking that he had gone through a sufficient thick-

ness of limestone, and that there was then no chance of finding ore. Other parties followed, having a knowledge of the geology of the district, and, perceiving the error of their predecessors, put down a bore to the position shown by No. 2, and found a magnificent bed of ore in the first limestone, and another in the second limestone.

Another case, showing the ridiculous errors which may be committed by those who have not taken the trouble to make

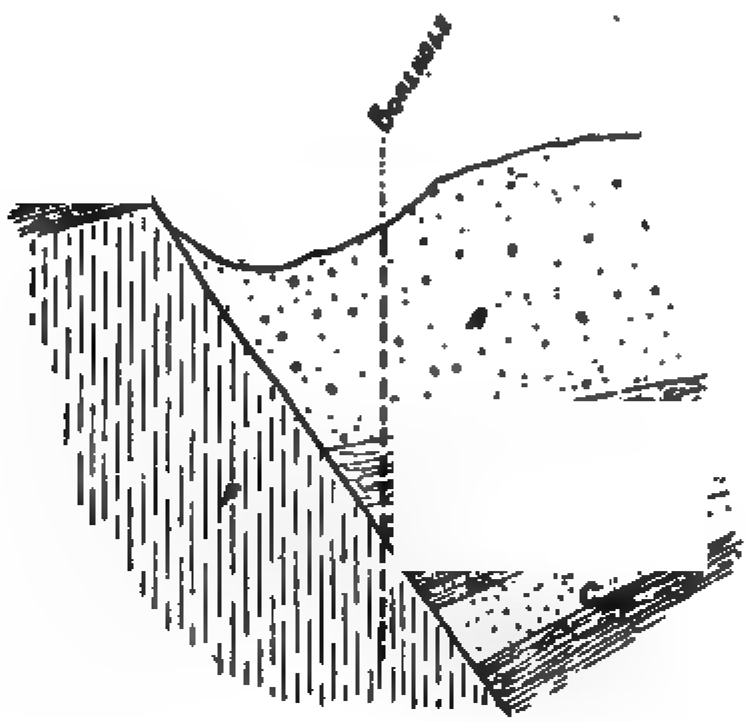

FIG. 26.—SECTION NEAR YEATHOUSE.

References—*A* St. Bees Sandstone. *B* Breccia. *C* Millstone Grit. *D* Limestone. *E* Lower Limestone Shale. *F* Skiddaw Slate.

themselves acquainted with the structure of the district they are exploring, was of a borehole being stopped in a dark shale belonging to the coal measures, under the impression that it was in Skiddaw slate. This latter rock must have been at least one thousand feet below the bottom of the hole.

These are a few instances, among a great many, of the positive waste of money by those who have a supreme contempt for geology, and, who think that their acquaintance with the methods of extracting ore in the mine is a sufficient

justification for their undertaking work that requires an entirely different training and special qualifications.

Let us look now at some of the facts that have been observed in working the deposits of these districts, and which may be safely and profitably recognised as guides in searching for hæmatite.

First among these is the fact that most deposits occur by

FIG. 27.—SECTION OF PALLAFLAT MINE.

References—*A* Surface Deposit. *B* Breccia. *C* Millstone Grit. *D*I *D*II *D*III *D*IV 1st, 2nd, 3rd, and 4th Limestones respectively. *E* Hæmatite.

the side of faults. It follows, therefore, that in looking for hæmatite our operations should be carried on alongside some fault, the larger the better.

Another well-ascertained fact is, that all the large deposits, unless interfered with by east and west faults, have a north and south direction, as also have the small "guts" or "ginnels," and strings of ore which frequently occur quite apart from faults. This suggests to us that, in boring, our holes should

be disposed in an east and west direction. If they be placed in a north and south line it is quite possible that two or more of them might pass into a mere "gut" or "ginnel" of ore, which, although of considerable thickness, would probably be only a few inches wide. Erroneous conclusions might in this way be arrived at, and large sums of money be absolutely wasted. Cases of the kind have actually occurred.

Some deposits are vein-like, others bed-like. In the Whitehaven district the former occur almost exclusively in the fourth or Clints limestone, whilst the latter are found in all limestones except the fourth. In Furness bed-like deposits do not occur.

In searching for a vein-like deposit the boreholes should be placed much nearer together (in an east and west line) than when looking for a bed-like deposit, for reasons already given when dealing with veins and beds. When speaking of the former, it was stated that boring was not the best means of searching for veins, nor is it so, if drifting can be resorted to, as it generally can in mountainous countries; but in a district like that of Whitehaven, where the surface is not very uneven, drifting is impossible as a means of search until a shaft has been sunk. Sinking is, however, much too costly to be entered upon until a deposit has been found, except in a district like Furness, where the ore frequently occurs just below the boulder clay, often only a few fathoms thick. There, small shafts, about four feet square, inside of wood, are frequently sunk in search of ore; but in the Whitehaven district the ore, as a rule, lies much deeper, and is overlain at times by a considerable thickness of solid rock, so that boring is generally employed in this district, even when searching for vein-like deposits, as being the best and cheapest in all the circumstances.

As already pointed out, iron ore occurs in all the seven limestones of the Whitehaven district, and sometimes we meet with workable deposits in two or three limestones in superposition, as, for instance, in the first, second, and third limestones, the third, fourth, and fifth, or the fifth, sixth, and seventh;

but notwithstanding the large number of boreholes that have been put through the whole thickness of the limestone formation to the Skiddaw slate, there is not a single instance of a good workable body of ore having been found in the seventh limestone where the whole formation is on. Some people, because they know that ore is met with in each of the seven limestones, say, "Oh, go to the slate," irrespective altogether of the thickness of the limestone overlying the slate, and in opposition to all experience. The futility of going to the slate, when the whole limestone formation has to be passed through, was pointed out by the author, in the *Colliery Guardian*, eighteen years ago; and although, in the interval, some hundreds of deep bores have been put down, yet not one of them has found a good workable body of ore in the seventh limestone, where all the seven beds had been passed through.

The author must not here be understood to say that iron ore does not exist in the seventh limestone when that is overlain by the other six beds, but rather it has not yet been proved in large remunerative bodies in that position, notwithstanding the many attempts that have been made to find it.

Hitherto we have spoken only of explorations from the surface. In the mine they may be somewhat varied, as it will then be possible to search for vein-like deposits by means of drifts. Even bed-like deposits may occasionally be sought in that way by drifting through a fault.

In putting down boreholes, the work is sometimes let at so much per fathom, according to the nature of the strata passed through, but the better practice is to let it by the fathom, irrespective of the kind of ground cut. In that way we are more likely to obtain an accurate account of the rocks passed through, which is of the utmost importance to the explorer. Journals of boreholes put down by contractors, under the first mode of payment, have been handed in that were purposely made inaccurate, so as to obtain a higher rate of remuneration, the shale beds being reduced to a minimum or suppressed altogether, whilst the limestones, for which much more was paid on the first system, were correspondingly exaggerated in thick-

ness, so that it was impossible for any one even to guess the geological horizon at any particular part of the bore, although any one acquainted with the succession of rocks in the district would have detected the fraud. Such a hole is absolutely useless, unless by accident it should pass through ore; but, even in that case, it affords very little help in fixing the position of the next bore.

It may here be mentioned that in a few cases in the Whitehaven district a double rate of remuneration was paid to the boring contractor when passing through iron ore. This was done with the intention of securing accurate samples of any deposit passed through, but it more frequently led to dishonest returns; and instances have come under the author's notice where large sums of money have been uselessly expended in sinking to the ore shown in these fictitious returns.

CHAPTER III.

THE WORKING OF IRON ORES.

THIS branch of our subject will perhaps be most concisely dealt with under the three heads adopted in the preceding chapter—viz., veins, beds, and irregular deposits.

It is not intended to describe the various mechanical appliances employed in working iron ore, as these are practically the same as those used in coal mines, and have frequently been described before. The object now aimed at is to give a concise outline of the methods of extraction usually followed in working deposits of different kinds.

VEINS.

Deposits of this nature frequently occur in mountainous regions, where it is possible to work by means of " day " levels—that is, levels driven into the mountain side directly on the line of the vein, or the latter may be reached by means of crosscuts. In such a case, levels or drifts are made at vertical intervals of sixty, eighty, or one hundred feet, or more, according to the character of the ground. If that be steep, and crosscuts are necessary, they will not be long so that they may be made at more frequent vertical intervals. If the levels commence on the vein, the inclination of the surface is not so important, and the distance apart of the levels will be determined by other considerations.

Sometimes it is found necessary, from the nature of the ground, to sink one or more shafts, and from these to drive

out levels, to the vein, at suitable intervals. Most of the veins in Cornwall, Devon, and West Somerset have been worked in this way. So also have some of the veins of Cumberland. But whether worked by day levels or by shafts the principle is the same, although, other things being equal, it is an advantage to work by day levels, as any water that may enter the mine can then pass out by gravitation, in which case the cost of pumping, sometimes very serious, is altogether avoided. At times it is desirable to adopt a combination of shafts and day levels, the latter being arranged to

FIG. 28.—LONGITUDINAL SECTION OF VEIN-WORKINGS.

References—A Main Levels. B Intermediate Levels. C Rises. Ore.

carry off the water, the former to deal most advantageously with the output of ore.

Figure 28 shows the manner in which a vein in steep ground is opened out by means of main levels, intermediate levels, and "rises." This principle is practically carried out in the same way even if shafts have to be employed. Owing to the irregular manner in which ore occurs in these veins,—that is, as lenticular masses of various dimensions and at various intervals,—the disposition of the levels and "rises" may not often have the regularity they present in the above section, but will be located according to circumstances, always bearing in mind that the intermediate and main levels are intended

to lay open the ore bodies, while the "rises," although useful for the same purpose, when they can be conveniently made in ore, are mainly arranged for ventilating purposes, and for the transference of ore and rock from the intermediate to the main levels.

The ore left in the ground between the levels and "rises" is removed, in due time, by the process known to miners as "stoping," commencing in the back of a level and working upwards. The space left by the removal of the ore from these "stopes" is sometimes filled with rubbish from a higher level as the stoping proceeds, the workmen standing on the accumulating rubbish. At other times, there is sufficient rock broken with the ore from the vein to serve this purpose. In some cases, however, the cheeks of the vein have to be kept apart by timber. To keep open the levels and rises, whilst in use, also requires a considerable amount of timber in some veins. Others, again, need very little.

In most veins the ore is so narrow that it can be removed by a single working at any level. In others, like some of the bedded-veins in the south of Spain, it is so wide (30 to 60 feet and over), that the workings on each tier are conducted on the pillar and stall system, as will be explained later on when describing the working of irregular deposits.

Spain.—Some of the larger veins in Spain have been extensively quarried near the surface, and so enamoured are the Spaniards of this method of working, that they have sometimes continued it long after it could be shown to be wrong, both from a monetary and a mining point of view. It is a comparatively simple matter to say when it is commercially wise to stop quarrying and commence mining. The depth to which a quarry may be carried so that the cost shall not exceed that of mining depends—1st, upon the width of the vein; and 2nd, upon the nature of the walls and the cost of sloping them back. The rapid manner in which the cost increases with the depth is illustrated by the dotted lines in Fig. 29. Of course the "batter"

to be given to the quarry walls will depend entirely upon the character of the rock.

Alston Moor, etc.—Some veins in this country have also been quarried on the back, but not to any great extent; for the ore, as a rule, is not wide, and therefore the cost of quarrying soon becomes excessive. Some of the limonite veins of Alston and Weardale have been wrought in this way for a few fathoms in depth. In the Lake district, in Cornwall, Devon,

Fig. 29.—Section Showing Rate of Increase of Overburden in Quarrying Veins.

References—A Walls of Vein. B Vein of Ore.

and Somerset, veins have also been quarried near the surface. The deeper ore, in all cases, was mined.

"Edge" Coals and Ironstones of Scotland.—The blackband ironstones of the Lothian coalfield, although in reality beds, are tilted at such high angles, that they are somewhat like veins, and the method of working them is so similar to that adopted in the case of veins, that it may be fitly described here. Figure 30 is a cross section of one of these seams, showing in dotted lines some of the different tiers of

workings, which are carried about twenty feet apart vertically. Figure 31 is a longitudinal section of the levels, showing the manner in which they are put out from the shaft. The latter, it may here be mentioned, is sunk on the inclination of the beds.

In working the coal and ironstone, shown in section Fig. 30—for the two minerals are wrought together—the miners "hole" in the "duff" or soft shale, under the coal, the *débris* from the holing being thrown into that part of the working, *a*, Fig. 31,

FIG. 30.—SECTION OF "EDGE" COAL AND IRONSTONE WORKINGS. (Scale 20 Feet to an Inch.)

References—A Black Band Ironstone. B Coal. C Duff (soft shaly matter). D Shale.

which is under the level of the road, as is also any other rocky material which it becomes necessary to cut away in making room for the "hutches" to travel. The coal is first wedged off, then the ironstone, no explosives being used.

BEDS.

Northamptonshire, etc.—When beds come out to the surface at a low angle, and have very little cover, they are usually worked opencast, as is the case with the ores of the

secondary rocks in Lincolnshire, Leicestershire, Northamptonshire, and Wiltshire. The process is exceedingly simple, and is illustrated by Fig. 32. The soil, sand, and gravel or other covering is stripped from the ore for a few yards in breadth along the line of the intended quarry face. The *débris* is deposited in any convenient place, and sometimes levelled and covered with the soil again. Then the working of the ironstone begins. After the quarry face has been carried back a few yards, a further area is stripped of soil, etc. This is deposited to the rear of the working face in the position shown at D, Fig. 32. So is any refuse from the ore bed. This latter sometimes amounts to as much as 30 per cent. of

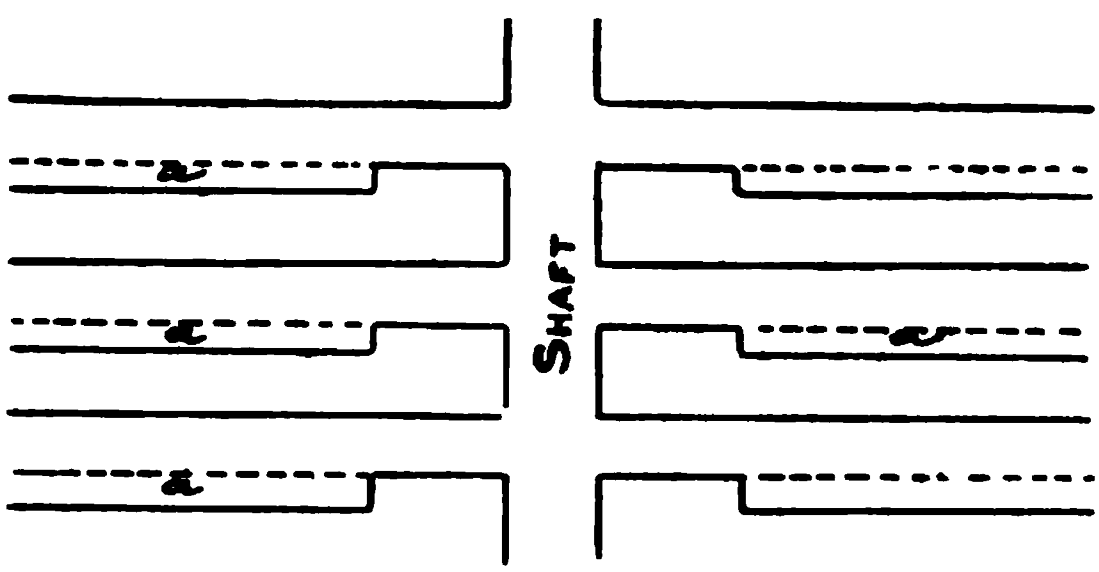

FIG. 31.—LONGITUDINAL SECTION OF WORKINGS IN EDGE COAL AND IRONSTONE MEASURES. (Scale 50 Feet to an Inch.)

the whole bed, and consists mostly of small ore, which, on account of its mechanical condition, is not sent to the furnaces. The "gulls," or clay walls, and the calcareous layers sometimes occurring in the ore, are also deposited in the rear, as described. The ore is filled in wagons with forks instead of spades, so as not to take up the finer ore.

Every time a fresh area of ore is uncovered, the material removed is placed in the same relative position. In some cases the top of it is ultimately levelled and re-soiled, so as to convert it into agricultural land again.

Ironstones of Cleveland and Lincolnshire, etc.—

When a bed of ore is overlain by a considerable thickness of cover, as in Cleveland, and at Claxby, in Lincolnshire, or where the overburden becomes too thick to remove, as near the city of Lincoln, or at Fawler, in Oxfordshire, the ore has to be mined. In such cases one or more levels are driven straight into the ore from "day." When well under cover, cross levels are put off on each side, and the bed thenceforward worked on the system known as "pillar and stall" or "stoop and room"; the pillars are made either square or rectangular. The height of the levels usually corresponds with the thickness of the bed, unless it be necessary to leave some ore on to form a better roof, or because of its inferior quality. The width of the levels varies from 6 to 15 feet,

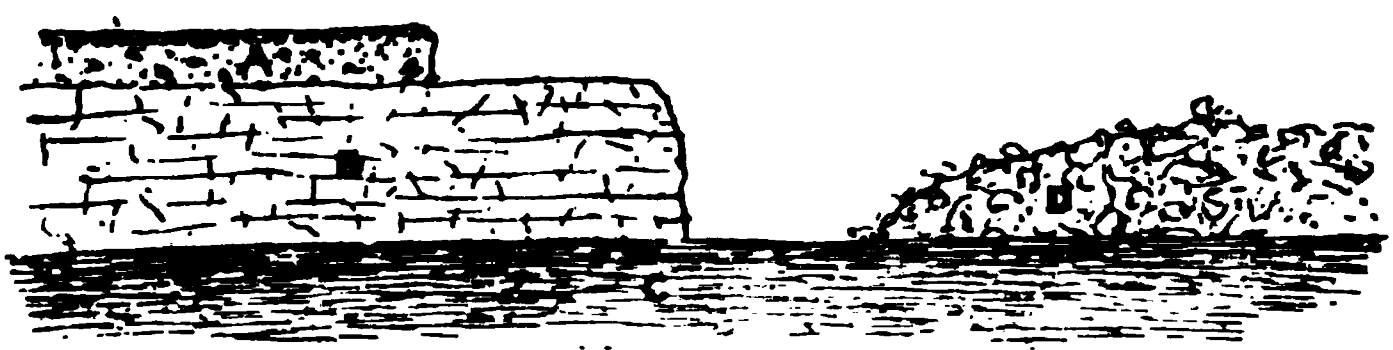

FIG. 32.—SECTION SHOWING MODE OF WORKING NORTHAMPTON ORE, ETC.

References—A Sand and Gravel. B Ore Bed. C Blue Clay. D Debris (redeposited overburden, etc.).

and the size of the pillars from about 30 or 40 to 60 feet square, and upwards, depending upon the thickness and character of the overlying rocks, and also upon the nature of the ore-bed.

More or less timber is needed to support the roof of the levels, the quantity varying with the nature of the ground to be kept open. Much of this can be drawn and used two or three times over. In Cleveland steel girders are sometimes used, in place of timber, in the main roads.

When explosives are necessary powder is used, as being superior to dynamite for this class of work. The holes, unless bored by machinery, are almost invariably "jumped" by a loaded drill, and are mostly triangular in section.

In time the pillars are removed. This operation requires an additional quantity of timber; in some cases oak "chocks" are used, which can be withdrawn when no longer needed and carried to another pillar.

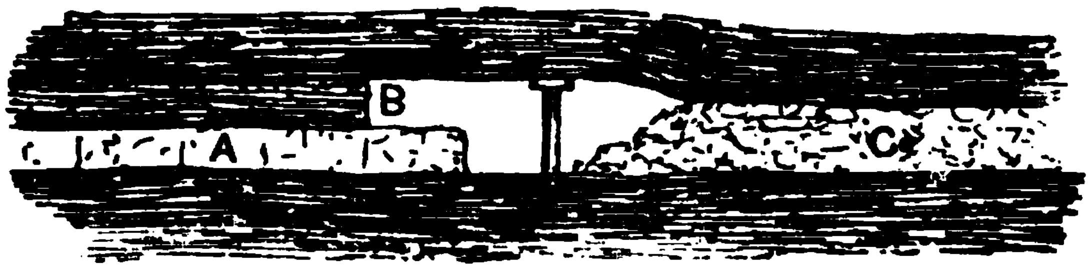

FIG. 33.—SECTION ACROSS FACE OF LONGWALL WORKING.

References—A Ironstone. B "Holing." C Packed "Gob" or "Goaf."

In Cleveland much of the ore is worked by shafts as well as by day levels, as already mentioned in Part II.

Clay Ironstones of Scotland, etc.—Thin beds, like the clayband and blackband ironstones of Scotland, etc., are usually worked on the system known as "longwall." In this way the whole of the bed is removed at once. The nature of the

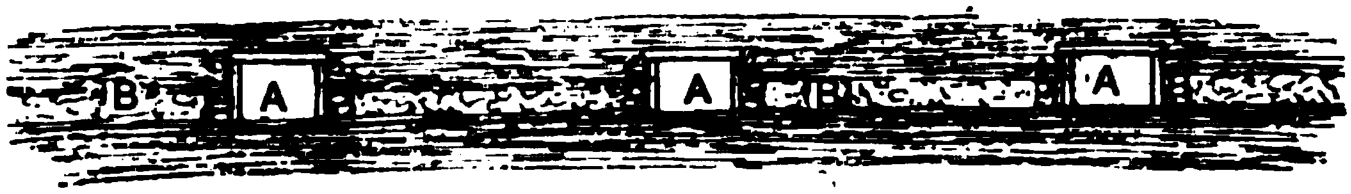

FIG. 34.—CROSS SECTION OF LONGWALL WORKINGS. (Scale 30 Feet to an Inch.)

References—A "Trailing" or "Drawing" Roads. B Packed Goaf.

work will be understood by reference to Figs. 33, 34 and 35. Figure 35 is a plan showing some of the roads leading to the working faces, and the packed "gob" or "goaf" between those roads. Figures 34 and 33 are vertical sections on lines *a b* and *c d* respectively.

The holing is sometimes done on the top of the stone, at other times below it. The ore is then wedged up or down, or shot-holes are put into the roof or sole, and the ore blasted

by powder. The *débris* which comes from the "holing" is thrown behind the workmen to assist in keeping up the roof. Sometimes this is in excess of what is needed for the purpose. It has then to be sent up the pit. In working some of the nodular ironstones of Staffordshire and elsewhere, as much as a tub of shale is sent up the pit for every tub of ore.

The larger blocks of shale coming from the upper or lower part, as the case may be, of the haulage roads, leading to the longwall faces, are used for building the walls on each side of those roads, to support the roof, as shown in Fig. 35. In addition to these walls, timber is used both in the roads and

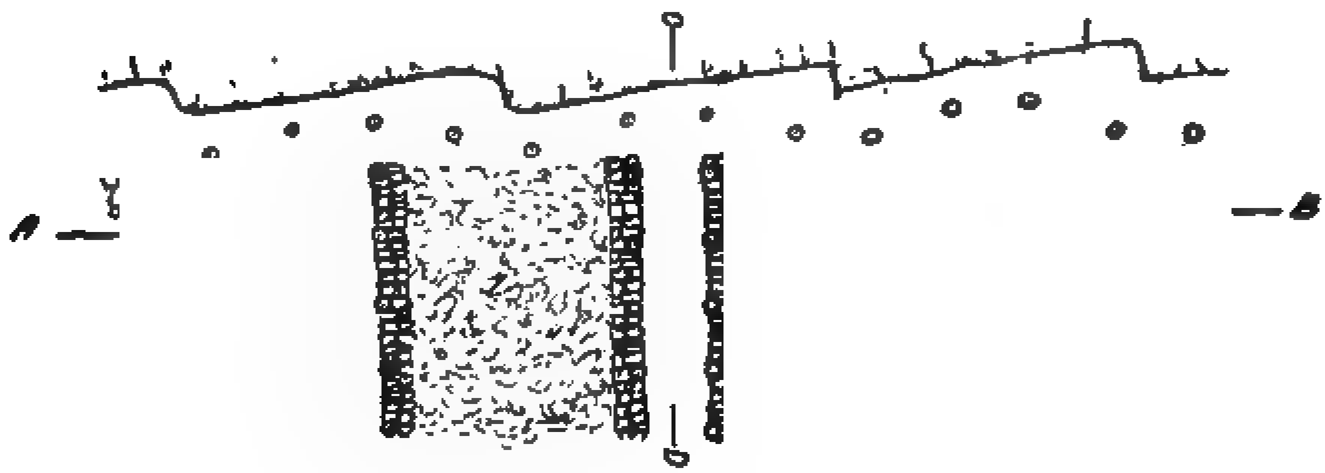

Fig. 35.—Plan of Longwall Workings. (Scale 30 Feet to an Inch.)

immediately behind the working faces, as shown in Figs. 33 and 34.

The outcrop of the nodular ironstones in Derbyshire, Staffordshire, etc., have been largely worked "opencast," or by what are known as "bell" pits.

Antrim.—In the Antrim mines, which are worked partly pillar and stall, but mostly longwall, it is unnecessary, as a rule, to "hole," the ore being of such a nature, generally, that it can be dug out by the pick. Explosives are only used in the neighbourhood of a "dyke," where the ore has been fused, and is consequently harder. When possible, the thin clay lying between the ore and basalt roof is left on. Sometimes,

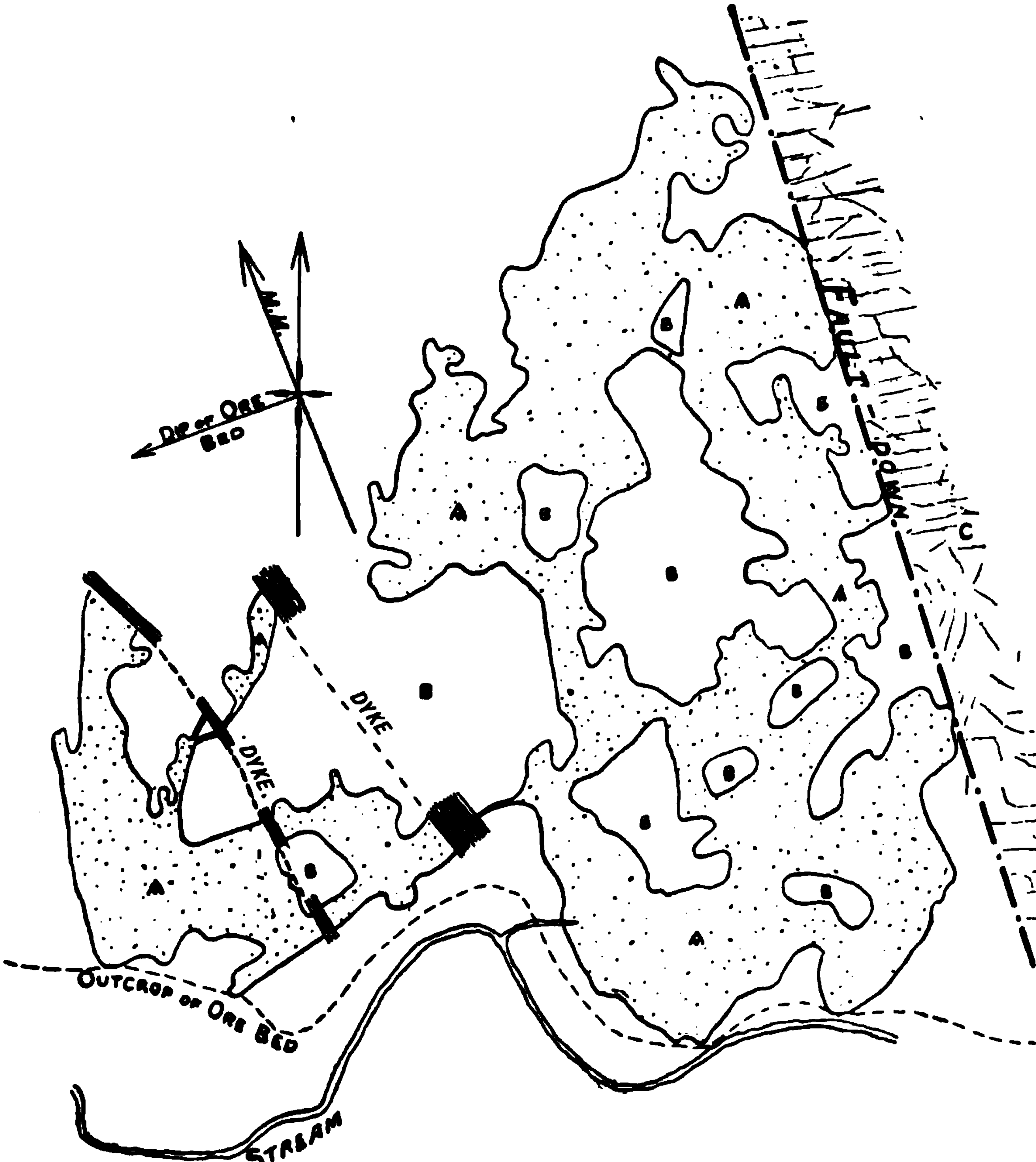

FIG. 36.—PLAN OF DUNGONNEL MINE. (Scale 462 Feet to an Inch.)

References—A Ore Bed worked. B Ore Bed too thin to work. C Basalt.

however, it falls. It is then thrown into the "goaf" behind the workmen, or otherwise disposed of in the mine.

As a rule, the ore bed has a gentle rise to the north. The "day" levels are therefore generally driven from a southerly outcrop, so as to get clear of the water by gravitation. If the ore be worked to the dip, that is, from a northerly outcrop, which it seldom is, long expensive under-drifts have to be driven, to tap the bed at some distance in from "day," and this adds considerably to the cost of working.

Figure 36 is a plan of one of these mines, from which it will be seen that a certain proportion of the ore has to be left, being too thin to work. The quantity of ore raised from the area exhausted in this mine was about 6,000 tons per acre, the average thickness being about 16 inches.

Irregular Deposits.

Most deposits of this class, when mined, are worked on the system known as "pillar and stall"; some, however, are quarried.

Devon.—The dish-like deposits of limonite occurring near Brixham were worked opencast.

South Wales. — The upper part of the deposits at Llanharry, Bute, and Mwyndy, in South Wales, were also worked opencast, the deeper portions being mined.

Bilbao.—The Bilbao deposits are all quarried, being very near the surface. Most of them have only a thin covering of soil and rocky *débris*, although some, such as those on the Triano Mountain, are overlain by shale or limestone. These rocks, however, are thin as compared with the ore, and therefore they are removed, the deposit being afterwards quarried. Where the concessions are of small extent, and thickly crowded together, as on the Triano, a difficulty arises, in working these quarries, from want of space on which to deposit the overburden and the rock which occurs in association with ore. If the whole concession happens to contain ore, and arrangements cannot be made with a neighbour for

depositing the surface material, only a portion—say half—of the ore can be uncovered at once, the *débris* being placed on the remaining area. After a certain depth of ore has been worked, the rubbish, as well as the overburden lying on the unworked portion, is put into that hole, and the second part of the quarry worked down to the same level as the first. This process is several times repeated, until the bottom of the ore is reached.

In some cases, where there is depositing ground for the rubbish, nearly the whole thickness of the ore can be worked at once, as in the "Cæsar" mine, which was approached by a tunnel nearly on a level with the bottom of the ore. In such a case the ore is worked in steps or stages of about 30 feet in height, the working of the uppermost being the most advanced.

In these quarrying operations the explosive mostly used is powder, but in the rubio mines or quarries dynamite is used as well, for enlarging the bottoms of the holes so as better to concentrate the action of the powder. This enlargement takes place through the bursting of the walls separating the cells which are so numerous in rubio.

Rosedale, etc.—Irregular deposits are not often so situated that they can be worked by "day" levels, though some such cases are known, as, for instance, the magnetic ore of Rosedale and the hæmatite worked at Dalzell's Gutterby in the Whitehaven district. Both these deposits were worked on the pillar and stall system. In the latter mine there was only one tier of workings, but in the former the ore was thick enough, in places, to admit of three tiers being driven. Where the trough-shaped bodies of the Rosedale ore came out to "day" they were quarried, but the ground overlying the deposit rose so rapidly that the increasing thickness of overburden soon put a stop to that simple method of procedure, and the remainder of the deposit had to be mined by pillar and stall.

When it is not possible to quarry an irregular deposit, it is, as a rule, necessary to sink one or more shafts from which to work it, and that has been the practice in all the districts

hereinafter noticed. The situation of the shafts in relation to the deposit will be seen in Figs. 8, 10, 17, 19 and 20.

Forest of Dean.—In the Forest of Dean the shallower deposits, along the outcrop of the "crys", were worked opencast. A sketch of one of these old workings at Dean Pool, on the west side of the Forest, is given below.

FIG. 37.—VIEW OF AN OLD IRON ORE WORKING AT DEAN POOL.

The "churns"—that is, the deposits of deeper ore which have a rock roof—are, as a rule, of such dimensions that they can be exhausted in one operation, so that there is no need to leave any pillars. A peculiarity in connection with the working of these "churns" may here be mentioned, as it is quite unique, at the present day, in this country.

As pointed out in Part II., the churns are generally connected with one another by "strings" or "leads" of ore. These "leads" vary greatly in size, sometimes being a mere joint, at others widening out to a foot or two, or even more, then nipping in again, and they often take a very zigzag course through the rocks. In searching for "churns" these "leads" are followed from the main roads by small drifts, in places only just large enough for a man to pass through, in a crouching attitude. When a churn has been found these small drifts are often used for conveying the ore to the main haulage roads leading to the shaft. They are too small and often too steep to admit "carts," as the tubs or bogies are there called, so that the conveyance of ore through them is effected in the following manner. Small boys, called "billy" boys, carry the ore on their backs in boxes, called "billies." The sides of these "billies" are made of thin sheet iron, and the bottom, which is flat, of wood. The boys, without having any hold of the "billies" with their hands, go up and down ladders, and along other parts of the uneven and zigzag "billy" roads, at an astonishing speed, depositing their load of ore into "carts," which are then run in the ordinary manner to the shaft. Not much timber is necessary in the working of these mines, as the roads are usually driven in strong ground.

Furness.—In Furness, some of the shallower ore has been quarried, as at Plumpton and Martin, but generally speaking it has been mined.

We will now consider the method of working generally adopted. The main levels are put out from the shaft at about every ten fathoms, each level being opened out to the boundary of the ore on the principle of "pillar and stall." The ore drifts in any particular mine are, as a rule, made of a uniform size, because they have to be timbered. They vary, however, in different mines from 6 to 9 feet square inside of wood. In the size and form of the pillars there is no regularity, the drifts being turned in any direction to avoid stone, black muck, or clay. This irregularity is illustrated in

Fig. 38, which is a plan of one of the tiers of workings in a small mine opened out in this manner.

From the main levels, one or more vertical "rises" are put up near to the top of the tier of ore to be worked, and from these "rises" other levels are afterwards set off, working from the top downwards, in stages of 7 or 10 feet. The whole process is explained in Plate V. A. is a plan and section of a deposit of ore. B. shows a shaft sunk on the ore and the first

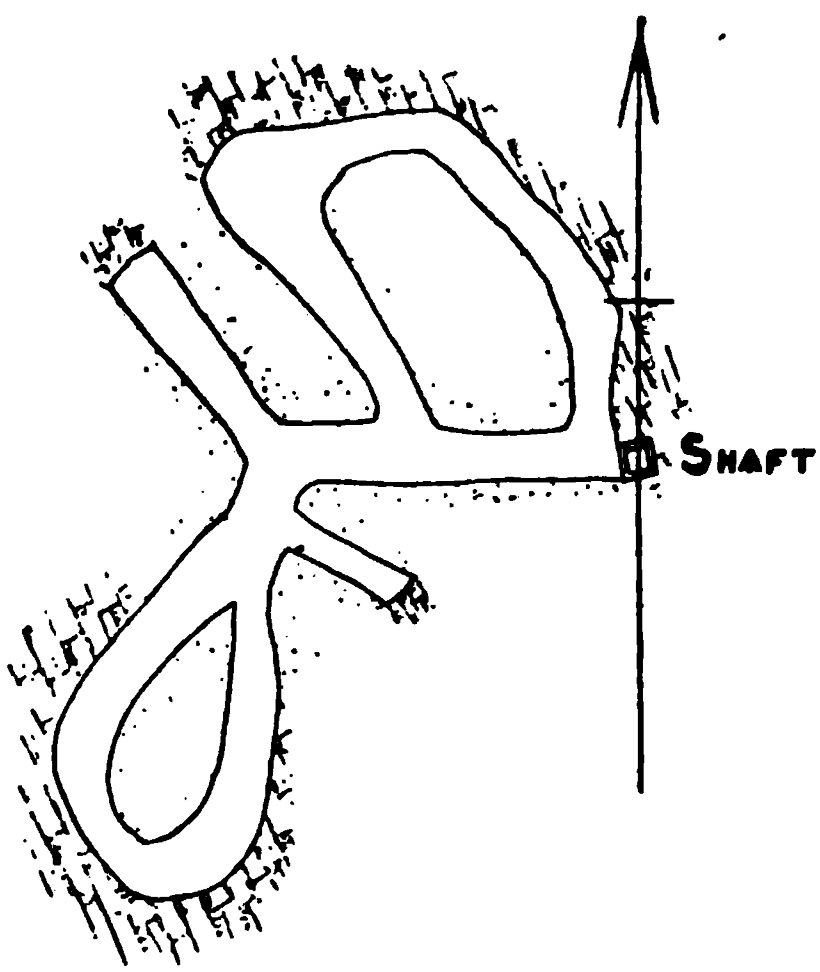

FIG. 38.—PLAN OF WORKINGS IN A FURNESS MINE. (Scale 60 Feet to an Inch.)

main level, with two "rises" therefrom, and drifts put out immediately below the superficial deposits. This tier is exhausted by removing the pillars in the manner shown in Fig. 39, which is a complete plan (after the removal of pillars) of the tier of workings shown in Fig. 38. The pillars are removed by taking off one cut after another, by timbered drifts, as indicated by the dotted lines in Fig. 39. After the exhaustion of this topmost layer of ore a lower tier is begun, as indicated in C., Plate V. By the time operations have gone

thus far the shaft has been deepened, and other main levels commenced. The exhaustion of the ore in the upper levels goes on uninterruptedly tier after tier, and, by-and-by, a state of things is produced somewhat similar to that shown in D., Plate V. No. 2 shaft being now in full operation the ore around the upper part of No. 1 shaft is removed, causing the latter to collapse. No. 2 shaft is, at the same time, sunk deeper, and eventually a section resembling E., Plate V., is produced. The second

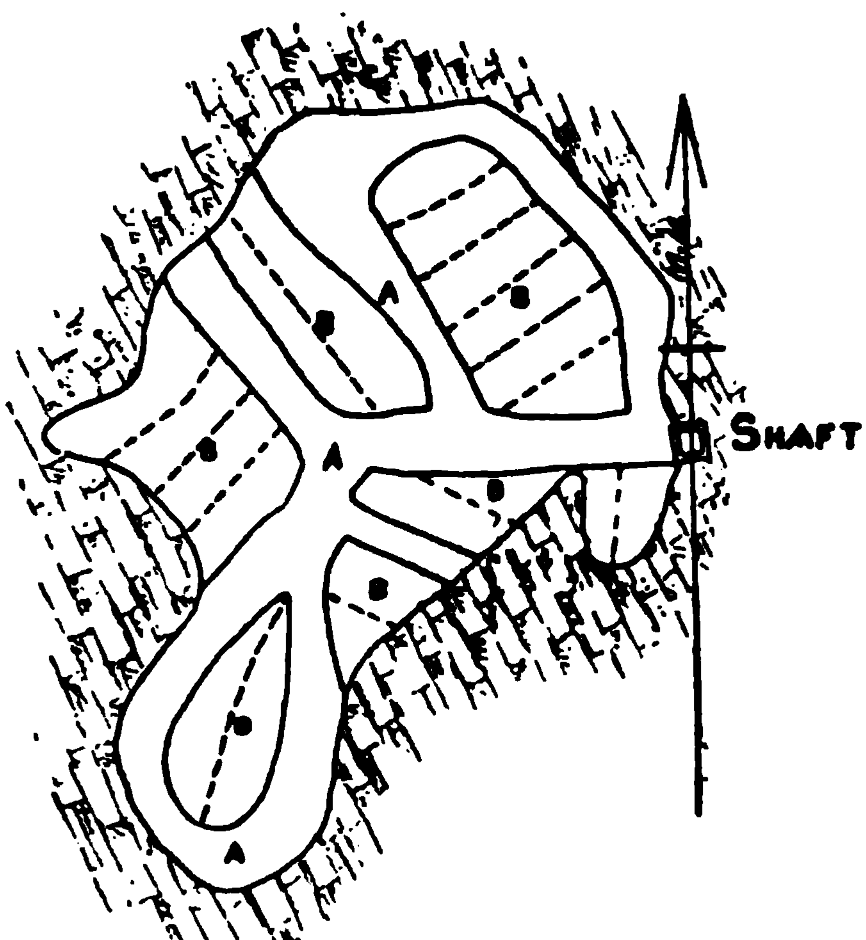

FIG. 39.—PLAN SHOWING METHOD OF "ROBBING" A FURNESS MINE. (Scale 60 Feet to an Inch.)

shaft is again deepened, another level driven out to the ore, and ultimately the deposit is exhausted. The surface, which has all the while been subsiding, as shown in the different sections, then appears as in plan and section F., Plate V., water in all probability collecting in the depression, owing to the stoppage of pumping operations.

If the approximate area of a deposit were ascertained by boring before sinking operations began, a shaft in the position of No. 1, A, Plate V. might be dispensed with, and the ore

exhausted from one in the position of No. 2. But as deposits of this kind are generally very near the surface, it is considered to be the better practice partly to prove the horizontal extent of the ore by means of a temporary exploring shaft sunk, it may be, somewhat in the position of No. 1.

The softer ore of Furness—*i.e.*, the greater part of the whole—is got mainly by the pick, a little dynamite or gelatine being used merely to loosen it. The harder ore is blasted.

The mode of setting the timber when working under a broken roof or "loose top," as is mostly the case, is shown in

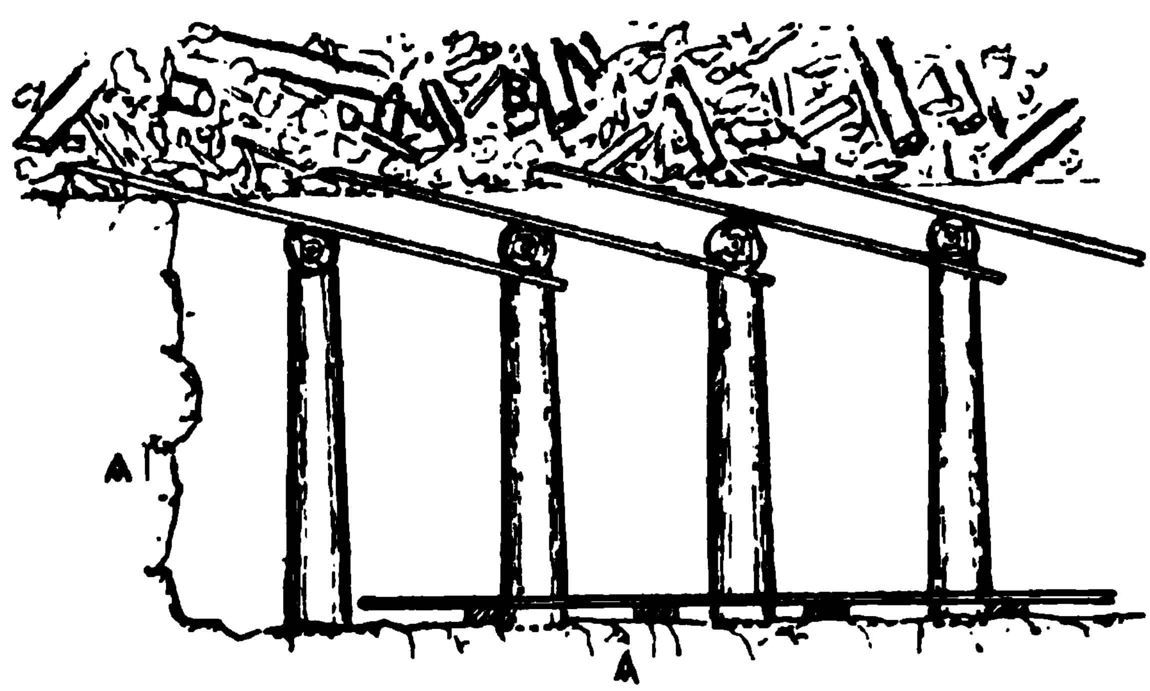

FIG. 40.—SECTION SHOWING MODE OF TIMBERING WITH A BROKEN ROOF OR "LOOSE TOP."

References—A Ore. B Sand, Gravel and old Timber, etc.

vertical section by Fig. 40. All the drifts in the soft ore have to be timbered, so have those in the harder ores that are worked with a loose top. But when the roof is hard and strong, timber is not required.

Cumberland.—In the Whitehaven district the mode of procedure differs considerably from that of Furness. Some of the ore here has been quarried, as at Todholes, Cleator, Crossfield, Montreal, and Bigrigg, but by far the greater part has been mined.

We will take the bed-like deposits first, as being simplest.

These, as a rule, are opened out by workings of the full height of the ore, and from 10 to 30 feet, or more, wide, according to the nature of the roof. No distinction is made between "headways" and "bordways."

The courses of the workings are, in a great measure, determined by the character of the ore bed. If it be free from stone, they may be carried parallel to one another and at right angles, so that the pillars are either squares, 25 to 30 feet on each side, or equivalent rectangles. But if, as more frequently happens, irregular masses of stone occur in the ore, then the workings may take devious courses, and the pillars be of different shapes and sizes.

In removing the pillars, it is usual to begin at the outer edge of the deposit and work back towards the shaft.

Those bodies of ore which, in Part II., are called "irregular-shaped deposits," are of much greater thickness than the bed-like deposits, and they are worked in floors or "eyes," to use a local expression. These "eyes" are usually about 30 feet apart—sole to sole—and the workings are carried 10 to 20 feet square, in section, according to the nature of the ore. This leaves a thickness of ore between the sole of one floor and the roof of the workings in the floor or "eye" below, varying from 10 to 20 feet. This ore is locally called a "middling."

When a deposit is free from stone the workings and pillars on the different floors may be kept exactly over one another, but usually this arrangement is disregarded, and the pillars of one floor may be standing directly over the workings of the floor below. Where the middlings are properly proportioned to the nature of the ore this can be done with impunity.

The pillars are taken out as in the bed-like deposits, commencing on the uppermost floor. The "middlings" are removed in a manner resembling that of working the Furness ore, beginning at the top, and proceeding by stages downwards. Then the next tier of pillars is removed, and so on to the bottom of the deposit.

The vein-like deposits, when wide, are worked in a manner

somewhat similar to the irregular-shaped deposits, but when under 20 feet wide they are wrought more like true veins. The ore then being so narrow, the full width of it can be taken at once; so that there is no need, and, in fact, no room, for pillars.

The main levels from the shaft are not often less than 60 feet apart vertically; but in working vein-like deposits intermediate levels are connected with them by means of "rises."

The first shafts sunk to work a deposit frequently collapse from the dragging of the ground, caused by the subsidence

FIG. 41.—SECTION SHOWING METHOD OF TIMBERING WITH A SOLID ROOF. (Ore at A.)

of the surface, or they may be located in the heart of a deposit, as shown in plan A, Plate V. In either case other shafts are sunk to replace them, in order to complete the exhaustion of the deposit or deposits.

All the ore is blasted, gelatine, gelatine-dynamite, dynamite, or gelignite, and occasionally powder being used, according to the nature of the ground.

Timber is, sometimes, not required in the first working; but more frequently it is necessary to use it. In taking out the pillars and "middlings" timber is used in large quantities. The mode of setting it in the first workings, whenever its use

is necessary, is shown in Fig. 41. In the "robberies," as the work of removing the pillars and middlings is called, it is often set as in Fig. 40.

All the methods of working, described above, are those usually followed, although, in special cases, they may have to be varied in accordance with the terms of agreement between lessee and lessor, or because of the particular conditions to be contended with.

CHAPTER IV.

WORKING COSTS AND SELLING PRICES.

AS might be expected, these vary greatly even in the same district, so that it will only be possible to deal with them in a general way. Working costs, moreover, depend largely upon the price of labour and materials, which also vary greatly in different districts and at different times, so that working costs, stated, as they often are, without any mention of the rate of wages or of the materials used, are of very little value at any time, and of no value whatever after the rate of wages and materials have changed. In the statements which follow this will be obviated, either by giving the rate of wages and materials on which the costs are based, or by stating the quantity of labour and materials necessary to get and place in a given position a given quantity of ore or rock of different kinds.

COST OF EXPLORATIONS.

This is exceedingly variable, and depends upon a variety of circumstances, such as the depth at which it is expected the ore will be found, the nature of the rocks to be pierced, and the locality in which the explorations are to be conducted.

Trenching. The cost of this work in ordinary surface materials, such as sand, gravel, and boulder-clay, may be reckoned, on an average, at about seven cubic yards per man per day.

Drifting and Sinking. These will be dealt with, in detail, when we come to consider the cost of such works in opening out a mine. In exploratory works sinking is, as a rule, only resorted to when the ore sought is immediately below the superficial accumulations.

Boring. The *actual* cost of boring is very variable even in the same class of rocks, and within a very limited area, arising from causes apart altogether from such variations as may be due to occasional accidents to the machinery. For instance, the ground may be very much more jointy at one place than at another, and pieces of rock may fall into the hole and jam the rods, causing great delay, and possibly the abandonment of the hole. Then again, the ground may be much harder at one place than at another, even if the rocks passed through have the same general character, or there may be a larger proportion of soft rock in one hole than in another.

Other things being equal, the cost per fathom increases with the depth, though we frequently find in boring through the same class of rock that this does not hold good, as the strata, although of the same kind, may be softer at a given depth than nearer the surface. Below is given the cost for labour alone of boring two holes, in different rocks, to a depth of 65 fathoms with an ordinary percussive machine actuated by a steam-engine and spring-pole. Two men and a boy attended to the machinery, etc., on each shift, and they worked two shifts of 12 hours each per day. There were no accidents of any moment to cause delay, so that the results may be looked upon as better than the average obtainable:—

	No. 1.			No. 2.		
	£	s.	d.	£	s.	d.
1st 5 fathoms	4	5	0	2	5	0
2nd " "	4	11	0	2	10	0
3rd " "	5	0	0	2	8	0
4th " "	6	9	0	2	19	0
5th " "	6	19	0	3	12	0
6th " "	8	6	0	4	8	0
7th " "	9	10	0	3	13	0
8th " "	6	0	0	6	14	0
9th " "	7	4	0	5	10	0
10th " "	7	10	0	4	2	0
11th " "	11	8	0	4	10	0
12th " "	10	0	0	4	16	0
13th " "	11	5	0	5	10	0
Total cost of labour	98	7	0	52	17	0

No. 1 was in carboniferous limestone with a few thin beds of shale. No. 2 in red sandstone. The average diameter of both holes was 4½ inches. They began 6 inches diameter and finished 4 inches. The total cost was as under:—

	No. 1. £ s. d.		No. 2. £ s. d.
Labour (two men and one boy at 12*s*. per shift)	98 7 0	...	52 17 0
Do. erecting and removing machinery	5 18 0	...	5 18 0
Coal (at 9*s*. 6*d*. per ton)	14 18 6	...	9 18 3
Tubes	4 10 0	...	6 10 0
Stores (oil, etc., for engine)	2 16 0	...	2 2 7
Water (at 6*d*. per 1000 galls.)	10 4	...	6 7
Sundries	4 10 0	...	3 10 0
Use of machinery	13 0 0	...	8 10 0
Total	144 9 10		89 12 5

The erection and removal of the boring plant may be put at eight or ten days each for two men and a boy, and a quarter of a day for a horse and man, if the distance does not exceed 100 feet.

In boring a series of holes, the above cost would probably be increased about 20 per cent. by accidents and other contingencies.

If the Diamond Boring machine be employed a great saving of time is effected, but it is more costly. Boreholes Nos. 1 and 2, above, were put down by a percussive machine, in 164 and 88 days (of 24 hours), respectively. By the Diamond Machine they could have been made in 36 and 24 days, respectively, but the cost, at the rates usually charged, would have been greatly increased.

Cost of Sinking and Drifting.

This varies with (1) the hardness of the rocks, (2) the size of the works carried out, and (3), in the case of sinking, with the quantity of water encountered.

With the cost of machinery and the plant generally required

about a mine, which is constantly changing but easily ascertained, it is not intended here to deal. We may, however, profitably inquire into the cost of sinking and drifting through the different description of rocks usually met with, such as boulder clay, limestone, sandstone, and shale.

Sinking. We will take a rectangular shaft of ordinary size, 14½ feet long by 6 feet wide, outside of wood, and the quantity of water not exceeding 20 gallons per minute. The cost, per lineal fathom, of sinking through the above-mentioned rocks, in ordinary circumstances, will then be as under:—

COST OF SINKING IN BOULDER CLAY.

Labour and Materials.	Quantity per fathom.	Rate.		Cost.		
		s.	d.	£	s.	d.
Sinkers and bankers	26 shifts	5	3	6	16	6
Dynamite	3·16 lb.	1	0	0	3	2
Fuse	32 ft.	0	0·25	0	0	8
Caps	11 caps	0	0·36	0	0	3·96
Candles	1·5 lb.[1]	0	4	0	0	6
Sharpening tools	10 pts.		0·5	0	0	5
Shafting "	1½ shaft		3	0	0	4·50
Total cost per fathom ...	...	...		7	1	11·46

These figures refer to a very stiff lower boulder clay. The ordinary superficial rocks, such as sand and gravel, or even the upper boulder-clay, may be sunk through at prices varying from one-half to three-fourths of the above. The cost includes the putting in of all necessary timber. The shifts are eight-hour shifts, in this as well as in all the following tables of costs, unless otherwise stated.

A small exploring shaft about 4½ feet square could be sunk in the same ground for about one-fourth of the above.

[1] The reason for the small quantity of candles used here is that the stratum sunk through was, as is invariably the case with this description of rock, near the surface, and candles could be dispensed with altogether for a few fathoms.

COST OF SINKING IN LIMESTONE.

Labour and Materials.	Quantity per fathom.	Rate.	Cost.
		s. d.	£ s. d.
Sinkers and bankers	78 shifts	5 3	20 9 6
Dynamite	28 lbs.	1 0	1 8 0
Fuse	264 ft.	0 0·25	0 5 6
Caps	95 caps	0 0·36	0 2 10·2
Candles	18 lbs.	0 4	0 6 0
Sharpening tools	110 pts.	0 0·5	0 4 7
Shafting "	1½ shafts	0 3	0 0 4·5
Total cost per fathom ...	...	...	22 16 9·7

This rock was what would ordinarily be considered a moderately hard carboniferous limestone. It did not require timbering, but the above cost included the putting in of three sets of bearers (six feet apart vertically) for the support of the slides. Some limestones may be sunk for three-fourths of the above cost, others will cost more, particularly if they be "loughy."

COST OF SINKING IN SANDSTONE.

Labour and Materials.	Quantity per fathom.	Rate.	Cost.
		s. d.	£ s. d.
Sinkers and bankers	30 shifts	5 3	7 17 6
Dynamite	21 lbs.	1 0	1 1 0
Fuse	172 ft.	0 0·25	0 3 7
Caps	62 caps	0 0·36	0 1 10·3
Candles	10 lbs.	0 4	0 3 4
Sharpening tools	64 pts.	0 0·5	0 2 8
Shafting "	⅜ shaft	0 3	0 0 2
Total cost per fathom ...	...	...	9 10 1·3

The above was a soft red Permian sandstone and had to be closely timbered. The labour involved in timbering is included in the cost. Some of the sandstones belonging to the mill-

stone-grit series are much harder, and cost nearly twice as much as that of which we have just given the particulars, which was perhaps as soft a sandstone as any likely to be met with.

Cost of Sinking in Shale.

Labour and Materials.	Quantity per fathom.	Rate.		Cost.		
		s.	d.	£	s.	d.
Sinkers and bankers	46 shifts	5	3	12	1	6
Dynamite	25 lbs.	1	0	1	5	0
Fuse	196 ft.	0	0·25	0	4	1
Caps	68 caps	0	0·36	0	2	0·48
Candles	13 lbs.	0	4	0	4	4
Sharpening tools	38 pts.	0	0·5	0	1	7
Shafting "	1⅛ shaft	0	3	0	0	4
Total cost per fathom ...	...	...		13	18	10·48

This was a compact, dark, slaty shale, but still it had to be timbered, and the cost of that work is included. Some of the more friable shales can be sunk for three-fourths of the above amount.

Drifting. Let us now consider, shortly, the cost of making a drift six feet wide by six feet high (inside of wood, when timbered) in each of the three kinds of rock last mentioned.

Cost of Drifting in Limestone.

Labour and Materials.	Quantity per fathom.	Rate.		Cost.		
		s.	d.	£	s.	d.
Miners and trailers	21 shifts	4	6	4	14	6
Dynamite	19 lbs.	1	0	0	19	0
Fuse	112 ft.	0	0·25	0	2	4
Caps	50 caps	0	0·36	0	1	6
Candles	8 lbs.	0	4	0	2	8
Sharpening tools	60 pts.	0	0·5	0	2	6
Shafting "	·83 shaft	0	3	0	0	2·5
Total cost per fathom ...	...	...		6	2	8·5

The examples given can only be taken as illustrative, for the cost varies not only with the hardness of the rocks, but with their dip, considered in relation to the direction of the drift. The presence of a fault or "cheek" along one side of a drift may also considerably affect the cost of the latter.

The limestone drift, of which particulars of the cost of driving are given on p. 377, was driven level, square across the beds and towards the dip. Some limestones may be driven for 25 per cent. less than this. Others would cost that much more.

Archean dolomite, when not weathered, costs 15 to 20 per cent. more than the above limestone.

COST OF DRIFTING IN SANDSTONE.

Labour and Materials.	Quantity per fathom.	Rate.		Cost.		
		s.	d.	£	s.	d.
Miners and trailers	17 shifts	4	6	3	16	6
Dynamite	6·5 lbs.	1	0	0	6	6
Fuse	60 ft.	0	0·25	0	1	3
Caps	20 caps	0	0·36	0	0	7·2
Candles	5 lbs.	0	4	0	1	8
Sharpening tools	18 pts.	0	0·5	0	0	9
Shafting "	$\frac{2}{3}$ shaft	0	3	0	0	2
Total cost per fathom ...	...	...		4	7	5·2

This was a coarse sandstone belonging to the grit series, but it was not hard. The drift was driven level, but towards the rise of the beds, and had to be timbered—but not closely—on account of the numerous joints intersecting it.

The cost of making a drift in shale is given on the opposite page. This drift was driven level, on the strike of the beds, and timbered, to keep back the sides. The roof was of limestone, and therefore did not need support.

Some shales can be drifted through with much less dynamite than the above—about $\frac{1}{2}$lb. per fathom being sufficient—but the quantity of labour is practically the same, more work having to be done, then, with the pick.

COST OF DRIFTING IN SHALE.

Labour and Materials.	Quantity per fathom.	Rate.	Cost.
		s. d.	£ s. d.
Miners and trailers	16 shifts	4 6	3 12 0
Dynamite	6·25 lbs.	1 0	0 6 3
Fuse	60 ft.	0 0·25	0 1 3
Caps	22 caps	0 0·56	0 0 7·92
Candles	5·5 lbs.	0 4	0 1 10
Sharpening tools	20 pts.	0 0·5	0 0 10
Shafting „	$\frac{1}{3}$ shaft	0 3	0 0 1
Total cost per fathom ...	...	...	4 2 10·92

Skiddaw slate, which is practically an indurated shale, may, when near "day," and much weathered, be driven for 50 per cent. less than the above cost. But when deep in the mine it costs, often, 85 per cent. more.

The same remarks apply to *amphibolite*, *gneiss*, and all rocks of a kindred nature, which are easily wrought near the surface, but become much harder in depth.

The *lithomarge* of Antrim may be driven for about $\frac{7}{10}$, and the *bole* or "pavement" for about one-half the cost given in the preceding table for shale—that is, if the quantities of time and materials be taken. The wages paid in Antrim are much lower than those given in the tàble referred to, and therefore the cost in money will be proportionately reduced. It must, however, always be borne in mind, throughout this chapter, when costs are compound, it is only with reference to quantities of time and materials, and not money values, for the reason explained at the commencement of the chapter.

COST OF WORKING ORE.

The total cost of working any given body of ore depends, very much, upon the output which can be obtained from it. If that be large, the rate per ton of ore, for all general charges, such as surface-labour, explorations, coals, and management,

is reduced, but if the output is small, these standing charges are correspondingly increased. There are some charges, however, which, so far as they affect the rate per ton, are independent of the output; such as the cost of breaking and "trailing" or "putting" the ore, and of the timber used in the working places.

The principal item of cost in working iron ore of any kind is that of getting the ore, whether it be blasted or dug by pick, so that this part of the subject will be treated in considerable detail.

In order to avoid repetition, it is proposed to consider this division of our subject under the following heads: (1) hæmatites, (2) limonites, (3) magnetites, (4) iron ores of the secondary rocks, and (5) argillaceous ironstones of the carboniferous rocks.

HÆMATITES.

Cumberland and Furness. Other things being equal the cost of working these ores depends upon their hardness, which is very variable in different deposits, as may be judged from the following particulars as to boring and blasting. The "jumper" or drill steel in general use for boring is $\frac{7}{8}$ inch diameter. The long jumpers are sharpened to $1\frac{1}{16}$ inch, short ones $1\frac{1}{4}$ inch. The depth of the holes varies from $1\frac{1}{2}$ to 3 feet, the average being about $2\frac{1}{4}$ feet, and they are mostly bored single handed, with a hammer about $4\frac{3}{4}$ to $5\frac{1}{4}$ lbs. weight.

In *hard compact ore* the time occupied in boring one of these holes has been known to take twenty-four hours, and 90 jumpers were blunted in the operation. But the average time, by selecting the softest convenient places, is about $9\frac{1}{2}$ inches per hour, and the jumpers blunted about 2·2 per foot. In the first workings one pick is blunted to every 75 jumpers, showing that the bulk of the work is done by blasting. When there is a shale bed under the ore which can be "holed," the proportion of picks to jumpers is about 1 to 9. The quantity of dynamite put into a hole, in driving the first workings, is, on the average, about ·22 lb., and it gets, in a working which has not

been "holed," about ·8 tons of ore; in other words, it takes ·27lb. of dynamite to get one ton of ore, in such a working.

Of this class of ore, a man in an eight-hour shift can blast, fill, and trail to a distance of about 50 yards, 1·2 ton.

The miners' cost per ton of ore for working a deposit of this nature, in which the workings are about 15 ft. wide and 10 ft. high, and in which no timber is required, and the ore has to be trailed or "put" to a distance of 50 yards, is as under:—

Labour and Materials.	Quantity per ton.	Rate.	Cost.
		s. d.	s. d.
Miners and trailers	·83 shift	4 6	3 8·82
Dynamite	·27 lb.	1 0	0 3·24
Fuse	2·27 ft.	0 0·25	0 0·57
Caps	1·25 caps	0 0·36	0 0·45
Candles	·34 lb.	0 4	0 1·36
Sharpening tools	3 points	0 0·5	0 1·50
Shafting "	·03 shaft	0 3	0 0·08
Total cost per ton	...	...	4 4·02

In removing the "middlings" and parts of the pillars, this cost would be reduced from 30 to 45 per cent., according to the quantity of timber that had to be used.

Loose, rubbly ore.—This class of ore, which, in working, breaks up into small pieces and fine powder, is also blasted; but after a good shot is put into it much more can be got by the pick than of the hard ore. This will be made clear when it is stated that 2 picks are blunted for every jumper, whilst in the hard ore the ratio is 1 pick to 75 jumpers. A hole can be bored in this ore 27 inches deep, in about half an hour if it be an "upper," and in about an hour if "wet." It will get on an average 1·9 ton of ore, with a consumption of about ·13lb. of dynamite per ton of ore. One jumper will bore seven to eight holes before it needs sharpening. In a working 10 feet square in section and timbered, a miner will set his timber, get, fill, and trail a distance of 50 yards, 3 tons of

ore in a shift of 8 hours, and the total cost of his work per ton is as follows:—

Labour and Materials.	Quantity per ton.	Rate.	Cost.
		s. d.	s. d.
Miners and trailers	·33 shift	4 6	1 5·82
Dynamite	·13 lb.	1 0	0 1·56
Fuse	·94 foot	0 0·25	0 0·23
Caps	·53 cap	0 0·36	0 0·19
Candles	·13 lb.	0 4	0 0·52
Sharpening tools	·4 points	0 0·5	0 0·20
Shafting „	·02 shaft	0 3	0 0·05
Total cost per ton	...	...	1 8·57

The cost of working out the pillars and middlings, in this class of ore, is practically the same as that of the first working, presenting, in this respect, a marked contrast to the reduced cost of pillar working in the hard ore.

The cost of working perhaps half the ore in the Whitehaven district may be taken to be about midway between the two cases just given, the quantity of ore got, filled, and trailed per man, per shift of 8 hours, being about 2 tons; 30 jumpers being blunted to 1 pick, and the quantity of dynamite used per ton of ore being about ·22lb.

In Furness, the hard ore is not so hard as that of Whitehaven, but it also is got by blasting, and the miners' cost of getting it is about 73 per cent. of that of hard Whitehaven ore.

The softer ore of Furness is got mainly by the pick, gelatine being used simply to shake it. A miner, in addition to timbering his drift (about 7 feet square inside of wood), can get, fill, and trail 50 yards, about 2¼ to 3 tons of ore per shift of 8 hours, and the quantity of gelatine he uses is ·015lb. per ton of ore; 1·4 picks are blunted to 1 jumper, and about 1 hole, containing ·15lb. of gelatine, is fired for every 10 tons of ore gotten.

The details of the miners' cost of an average deposit of this ore are given in the subjoined table :—

Labour and Materials.	Quantity per ton.	Rate.	Cost.
		s. d.	s. d.
Miners and trailers	·4 shift	4 6	1 9·60
Gelatine	·015 lb.	1 2	0 0·21
Fuse	·2 foot	0 0·2	0 0·04
Caps	·1 cap	0 0·36	0 0·03
Candles	·16 lb.	0 4	0 0·64
Sharpening tools	.6 points	0 0·5	0 0·30
Shafting „	·03 shaft	0 3	0 0·08
Total cost per ton	...	...	1 10·90

When any of these ores are quarried the miners' cost is reduced from 50 to 60 per cent.

Another important item of cost in the mining of these ores is timber. The quantity used varies greatly in different mines, and in different parts of the same mines. For example, in making the first workings in hard ore, if there is a solid top, scarcely any timber is used, whilst in the loose, rubbly ore of Whitehaven, it often amounts to half a cubic foot and more, whilst in the softer ore of Furness it reaches $\frac{5}{8}$ and $\frac{3}{4}$ of a cubic foot per ton of ore. Again, one part of a mine may be undergoing the process of "robbing," whilst another part is being opened out by the first workings. Now, in almost all robbery workings, a large quantity of timber is used, no matter whether the ore be hard or soft, and it may be taken, on the average, to amount to about $\frac{5}{8}$ of a cubic foot per ton of ore, where the ore is solid; if it be mixed with rock or *débris* the quantity of timber required, per ton of ore, will be increased.

Let us now consider the cost per ton, during first working, exclusive of royalty and way-leaves, of putting these ores on to trucks at the pit's mouth. As, however, many of the charges necessarily vary with the output, the examples given must only be considered as illustrative. We will take two

cases, one of a mine in hard ore, the other in loose, rubbly ore, both having an output of 150 tons per day, and not any water to pump.

Items of cost.	Hard ore.	Loose, rubbly ore.
	s. d.	s. d.
Miners' cost	4 4·02	1 8·75
Surface wages	0 4	0 4
Explorations and other dead work ...	0 5·5	0 5·5
Timber	0 0·5	0 6
Coal	0 1	0 1
Stores	0 3	0 3
Rates and taxes	0 2·9	0 2·9
Management, etc.	0 2·5	0 2·5
Total cost per ton	5 11·42	3 9·65

WAGES ON WHICH THE ABOVE COST IS BASED.

	s. d.		s. d.	
Miners	4 6	to	5 0	per day
Underground labourers ...	3 6	"	4 0	" "
Bankers	4 0	"	4 6	" "
Surface labourers	3 4	"	3 6	" "

Bilbao. The hæmatite in the Triano Mountain is quarried. A man can get and fill in 10 hours about 4¼ tons. The explosive mostly used is powder. Delivered on board ship, in the river, the cost per ton, exclusive of royalty, is approximately as under, for an output of about 250 tons per day.

	s. d.
Removing over-burden, etc. (varies with thickness) say	0 5
Getting and filling ore,[1] (labour only) ·24 day at 2s. 9*d*.	0 7·92
Explosives and tools...	0 4
Carriage by rope tramway to "deposit" at Ortuella,	0 8
Carriage by rail from Ortuella to ship	1 8
Management and sundry charges	0 3·75
Total cost per ton	4 0·67

[1] The filling alone is done at the rate of about 1 ton in 6 hours per man.

WAGES ON WHICH THE ABOVE COST IS BASED.

	s.	d.		s.	d.	
Drillers and shot-firers ...	3	6	to	4	0	per day
Labourers	2	0	„	2	6	„ „
Women	1	8	„	1	11	„ „
Boys	1	3	„	2	0	„ „

LIMONITE.

Deposits of this ore occurring in limestone, similar to those of Trecastle, Mwyndy, and the Forest of Dean, may be wrought at approximately the same cost as hæmatite, having a similar physical condition, and therefore it is not necessary to notice them separately.

The limonites of the secondary rocks will be dealt with later on. Those of Bilbao cost more to work than the hæmatites of that region. The excess is entirely in the extra labour of getting and filling, which is sometimes double that required to work campanil, partly on account of the harder nature of the limonite or rubio, and partly because, being cellular, it is more difficult to blast, and also because it needs more care in selection than campanil.

Antrim. This ore, as already stated, is worked almost exclusively by the pick. A man can get, fill, and trail a distance of about 50 yards, in a shift of 8 hours, from 2 to 4 tons of ore, according to the thickness and character of the seam. The total cost F. O. T. exclusive of royalty, with an output of 100 tons per day and a seam averaging 2 feet 1 inch in thickness, is as follows:—

	s.	d.
Miners' and trailers' wages ·33 shift at 2*s.* 6*d.* ...		10
Oil and sharpening		1·5
Underground haulage by horse		1
Driving main roads		6
Surface-labour (2*s.* to 2*s.* 3*d.* per day)		2
Timber, ·2 cubic feet		2
Explosives and stores		1·5
Carriage to railway		2·5
Management, rates and taxes and sundries ...		6
	2	8·5

Magnetite.

As we have no very important deposits of this class of ore in this country we will take those of the south of Spain. In the mine all holes are bored double-handed. The steel is partly 1 inch diameter and sharpened to $1\frac{3}{8}$ inch, and partly $\frac{7}{8}$ inch diameter sharpened to $1\frac{1}{8}$ inch. They can bore in this way, with the larger drill, at the rate of 1·25 feet per hour; with the smaller, about 1·7 feet per hour. In a working of hard ore free from stone 15 feet wide by 9 feet high, requiring no timber, a man can get, fill, and trail 50 yards, in a shift of 10 hours, 1·68 ton. The quantity of dynamite (No. 3) is about $\frac{1}{2}$ lb. per ton of ore. This large quantity is a result of the inability of Spanish miners to bore their holes in the best positions for throwing a good burden.

The miners' cost of this ore is as follows:—

Labour and Materials.	Quantity per ton.	Rate.	Cost.
		s. d.	s. d.
Miners and trailers	·59 shift	2 3	1 3·93
Dynamite	·5 lb.	0 7·4	0 3·70
Fuse	2·3 ft.	0 ·108	0 0·25
Caps	·73 cap	0 0·38	0 0·27
Oil	·24 lb.	0 5	0 1·20
Sharpening and shafting tools ...	...	...	0 0·50
Total cost per ton	...	...	1 9·85

In quarrying this ore a man will get, fill, and trail $2\frac{1}{2}$ tons per day of 10 hours' work, with a consumption of ·116 lb. of dynamite per ton of ore. Besides this quantity of ore he has to get about one ton of stone, which occurs in lenticular bands along with the ore.

The total average cost F. O. T. exclusive of royalty, when mined at the rate of 250 tons per day, is during the first working as follows:—

	s.	d.
Miners' and trailers' wages	1	10
Underground dead work	0	6
Surface wages	1	2
Timber (·25 cubic foot)	0	4
Coal	0	2
Stores	0	3
Management and sundries	0	8
Total	4	11

In taking out the pillars and middlings the cost for timber is more than doubled, but the miners' and trailers' wages are reduced about one-third.

RATE OF WAGES.

	s.	d.		s.	d.	
Miners'	1	8	to	2	3	per day.
Quarrymen	1	6	„	1	8	„
Pickers, men	1	2	„	1	4	„
„ boys	0	7	„	0	8	„

IRON ORES OF THE SECONDARY ROCKS.

Northamptonshire, Lincolnshire, etc. A large part of these ores is worked opencast, as already described. The cost of removing the overburden varies greatly. In some places, as at Frodingham, the cover is only loose sand, on an average 3 or 4 feet thick. In other places, as near Finedon, the ore is worked with a cover of 2 feet of soil and 13 feet of hard clay. At Hunsbury Hill, near Northampton, we find about the same thickness of cover, but there it is mostly a whitish sand; whilst near the city of Lincoln the limestone, stripped off the ore bed, was nearly 20 feet thick before mining operations were commenced.

Taking an average case, a man can break and fill about 10 tons of ore per day of ten hours. This is in addition to the rejected ore and rubbish which is thrown to the rear. The cost F. O. T. of an average deposit of this class of ore, exclusive of royalty and surface damages, from a quarry yielding about 270 tons per day, is as follows :—

	s.	d.
Baring (sometimes only ½d.)	0	2
Breaking and loading ore (·11 day at 3s. 9d.) ...	0	4·95
Haulage to railway by horse	0	2
Management and sundry charges	0	5
Total cost per ton	1	1·95

The cost of such a deposit as that at Frodingham is about 20 per cent. less.

When the same ore is mined by means of day levels, the headings being carried 9 feet wide, the bords 12 feet wide, and the output about 250 tons per day, the cost F. O. T., exclusive of royalty, is increased, as shown in the table below. A man can then get, fill, and trail to a distance of 50 yards only about 4½ tons per shift of ten hours! Very little powder is required, and the timbering is done by deputies.

	s.	d.
Miners' cost (·2 shift at 4s.)	0	9·6
Timbermen and other underground daywork ...	0	3·2
Haulage by horse	0	2
Surface labour	0	1·5
Timber (·2 cubic foot)	0	2·14
Stores	0	1·5
Management, rates and taxes, etc.	0	6
Total cost per ton	2	1·94

RATE OF WAGES.

	s.	d.		s.	d.	
Miners	3	9	to	4	0	per day.
Timbermen				4	9	"
Underground day-men ...	2	6	"	4	0	"
Labourers	2	0	"	3	4	"

Cleveland. When we come to the carbonates of this district the cost is slightly varied. In some cases a considerable quantity of water has to be pumped. A man, here, can get, break, and fill about 5½ tons of ore per shift; and he uses about ·37 lb. of powder and ·06 lb. of candles per ton of ore. The powder being fired by "squibs," neither fuse nor caps are used. The shot holes, when hand-bored, are triangular in

section, 1½ inch on side, and are made from 2 to 5 feet deep. They get, on the average, about 3 tons per hole. As one man does the drilling for two (the other doing the principal part of the breaking and filling), he has to drill about 11 or 12 feet per shift, which in good ground he can do at the rate of about 4 feet per hour. Machine drills are used in some of the workings. The holes, then, are about 1¾ inch diameter, and a good machine can bore about 300 feet per shift of 8 hours. Some of these machines are driven by water power, others by petroleum. The powder used with the machines is about ·4 lb. per ton of ore, and each hole throws about 2·9 tons of ore.

In all cases the trailing and timbering are done for the miners.

Argillaceous Ironstones of the Coal Measures.

The quantity of this class of ore that can be got, filled, and trailed, or "drawn," by a man, per day, varies very much. In the nodular ironstones of South Staffordshire and East Shropshire it ranges from 15 to 45 cwt., averaging about 25 cwt. in the former district and about 21 cwt. in the latter. In the thick blackbands of North Staffordshire it is about 50 cwt., whilst in Scotland it varies from 30 to 40 cwt. These figures show why, in the struggle for existence, Scotland and North Staffordshire have survived, whilst the other districts have decayed.

We will take as an illustration, the cost, exclusive of royalty, of getting clayband ironstone in Scotland 16 inches thick, with an output of about 150 tons per day from two pits.

	s.	d.
Miners' cost (·5 shift at 4*s.* 6*d.*)	2	3
Underground deadwork	1	0
" haulage		2·5
Timber, coal, and other stores		7·5
Surface labour		7·5
Management, rates and taxes, etc.		7·5
Total cost per ton	5	4

Blackband costs on an average about 54 per cent. more at the face, and about 42 per cent. more, in "bing," on the surface.

The cost of the working nodular ironstones may be taken to exceed the above from 24 to 36 per cent., and in some cases more. This explains why the working of these ores has been so largely suspended.

Cost of Timbering.

To be added to the costs previously given, when timber is necessary.

Shafts. 14½ feet by 6 feet inside of wood :—

	Cubic Feet per Fathom.		Cubic Feet per Fathom.
Lining and midwalls (3 in. thick) ...	79¾	4 in. thick	106
Corner racking (5 in. on side) ...	6	6 in. on side	9
Cleats (18 × 6 × 3 in.)	1	... ...	1
Slides (4 × 4 in.)	3	... ...	3
Total	89¾		119

Three-inch lining is used in jointy rocks, four-inch in shale, or boulder clay :—

Exploring Shafts. 4 ft. × 4 ft. inside of wood :—

	Cubic Feet per Fathom.
5 in. square framing, set 2 ft. 6 in. apart, centres ...	8¼
1 in. backing	10
1 in. sliding boards	3
Total	21½

Drifts. 6 ft. × 6 ft. (inside of wood) :—

	Cubic Feet per Fathom.
Heads and legs, set 3 ft. apart, centres	16
Cover-wood, 1¼ in. thick	4¼
Total	20¼

This is sufficient for some shale drifts, others need more. Limestone seldom requires timbering, and sandstone only occasionally.

In ore workings requiring timber, like most of those in Furness, the proportion of heads and legs to cover-wood, and the quantity of each per ton of ore, is, on the average, as under :—

	Cubic Feet per ton.
Heads and legs	·5
Cover-wood ($1\frac{1}{4}$ in. thick)	·11
Total	·61

Cost for Coals.

Up a shaft 50 fathoms deep, and with a pair of ordinary non-condensing coupled engines and Lancashire boilers working 8 hours per day, 1 ton of ore can be lifted by 12 lbs. of unscreened coal (containing 12 per cent. of ash), in addition to lowering and raising the workmen, and letting down the necessary timber.

With a compound condensing engine and Lancashire boilers 1,000 gallons of water can be raised up a shaft of the same depth by 18 lbs. of coal of the same quality.

Selling Prices.

Selling prices vary according to the quality and mechanical condition of the ore and the distance it is from the market.

Cumberland. The following is a list of the prices realised between 1866 and 1890 by an iron ore of average quality :—

		s.	d.		s.	d.	
1866	from	12	6	to	13	3	per ton.
1867	"	12	6	"	14	0	"
1868	"	13	0	"	14	0	"
1869	"	13	6	"	15	0	"
1870	"	12	3	"	14	0	"
1871	"	13	6	"	22	0	"
1872	"	25	0	"	31	3	"
1873	"	31	0	"	36	4	"
1874	"	20	0	"	29	0	"

		s.	d.		s.	d.	
1875	from	16	6	to	23	6	per ton.
1876	"	15	6	"	18	0	"
1877	"	14	0	"	17	3	"
1878	"	13	0	"	15	9	"
1879	"	11	6	"	16	3	"
1880	"	15	0	"	30	0	"
1881	"	13	0	"	16	6	"
1882	"	13	6	"	17	0	"
1883	"	11	3	"	13	0	"
1884	"	10	3	"	11	3	"
1885	"	10	0	"	11	0	"
1886	"	9	0	"	11	0	"
1887	"	9	3	"	12	0	"
1888	"	9	3	"	11	3	"
1889	"	10	4½	"	17	6	"
1890	"	10	6	"	15	0	"

It must not be assumed that these were either the highest or lowest prices in any of the years named. They are the highest and lowest at which ore was sold from one mine only; and of course it is quite possible that the proprietors might not be in a position always to sell at top prices. On the other hand, they might not be compelled always to sell when prices were lowest. In fact, the author knows this to be the case; but still the table is a very fair guide to the variations in prices which took place during the time it covers.

The average prices per ton obtained, F. O. T., at mines, for a first-class Cumberland ore are as under:—

	s.	d.			s.	d.	
1865 ...	12	5	per ton.	1878 ...	14	3	per ton.
1866 ...	13	3	"	1879 ...	12	6	"
1867 ...	13	6	"	1880 ...	19	7	"
1868 ...	13	8	"	1881 ...	15	9	"
1869 ...	14	5	"	1882 ...	15	0	"
1870 ...	14	0	"	1883 ...	13	9	"
1871 ...	19	9	"	1884 ...	12	9	"
1872 ...	28	6	"	1885 ...	12	6	"
1873 ...	33	6	"	1886 ...	12	3	"
1874 ...	26	9	"	1887 ...	11	3	"
1875 ...	20	8	"	1888 ...	11	6	"
1876 ...	17	0	"	1889 ...	13	6	"
1877 ...	15	9	"	1890 ...	12	6	

Furness. Average selling price of a medium quality of ore, F. O. T., at mines, from 1870 to 1890 inclusive:—

		s.	d.				s.	d.	
1870	...	11	0	per ton.	1881	...	13	6	per ton.
1871	...	14	6	„	1882	...	12	6	„
1872	...	23	9	„	1883	...	10	6	„
1873	...	29	0	„	1884	...	10	0	„
1874	...	22	9	„	1885	...	9	9	„
1875	...	17	9	„	1886	...	9	6	„
1876	...	14	6	„	1887	...	9	0	„
1877	...	13	3	„	1888	...	9	3	„
1878	...	11	6	„	1889	...	10	0	„
1879	...	9	9	„	1890	...	9	9	„
1880	...	15	6	„					

Cleveland. Below are the selling prices of this ore, at the pit's mouth, from 1875 to 1890:—

			s.	d.		s.	d.	
1875	... ...	...	4	0				
1876	... ...	from	3	4	to	3	9	per ton.
1877	... ...	„	3	0	„	3	6	„
1878	... ...	„	3	0	„	3	6	„
1879	... ...	„	2	9	„	3	3	„
1880	... ...	„	3	3	„	3	9	„
1881	... ...	„	3	0	„	3	6	„
1882	... ...	„	3	0	„	3	9	„
1883	... ...	„	3	0	„	3	6	„
1884	... ...	„	2	9	„	3	3	„
1885	... ...	„	2	6	„	3	0	„
1886	... ...	„	2	6	„	3	0	„
1887	... ...	„	2	8	„	3	2	„
1888	... ...	„	2	8	„	3	2	„
1889	... ...	„	3	0	„	3	6	„
1890	... ...	„	2	9	„	3	3	„

Lincolnshire. The silicious ores of this county realise, on the average, at the mine, about 20 per cent. more than the argillaceous ores of Cleveland. The calcareous ores of Frodingham about 40 per cent. less than the latter.

Antrim. Between 1873 and 1890 the price of this ore, at the mines, has varied, as shown in the following table:—

	Pisolitic ore. s. d.		Bole. s. d.
1873	9 2 per ton	...	4 9 per ton.
1874	9 0 „	...	6 3 „
1875	7 0 „	...	4 9 „
1876	4 3 „	...	3 9 „
1877	4 3 „	...	3 9 „
1878	4 3 „	...	3 9 „
1879	3 6 „	...	3 3 „
1880	3 6 „	...	3 3 „
1881	3 6 „	...	3 3 „
1882	4 2 „	...	3 6 „
1883	3 11 „	...	3 6 „
1884	2 11 „	...	2 9 „
1885	2 8 „	...	2 6 „
1886	2 9 „	...	2 6 „
1887	3 0 „	...	2 6 „
1888	3 4 „	...	2 9 „
1889	4 4 „	...	2 6 „
1890	5 4 „	...	2 9 „

Bilbao. The selling prices of campanil per ton, delivered at Glasgow, or equal, between 1873 and 1890, were as under :—

		s. d.		s. d.
1873	from	27 6	to	32 0 per ton.
1874	„	24 6	„	36 0 „
1875	„	19 0	„	26 6 „
1876	„	18 0	„	20 0 „
1877	„	17 0	„	19 6 „
1878	„	16 3	„	18 3 „
1879	„	14 0	„	17 0 „
1880	„	18 0	„	27 6 „
1881	„	16 6	„	18 6 „
1882	„	17 4	„	19 0 „
1883	„	14 3	„	16 6 „
1884	„	13 0	„	13 9 „
1885	„	12 6	„	13 6 „
1886	„	11 0	„	13 3 „
1887	„	12 7½	„	14 6 „
1888	„	14 0	„	16 6 „
1889	„	14 6	„	18 0 „
1890	„	17 6	„	19 9 „

The price of rubio has been from *6d.* to *2s.* *10d.* per ton less

than campanil. The great variations in the above prices are largely due to fluctuations in the freight, as shown by the following table, which gives the price per ton, F. O. B., Spain :—

	Campanil.		Rubio.	
	s.	d.	s.	d.
1882	7	2	6	8½
1883	7	2½	6	8½
1884	7	3	6	5
1885	7	2	6	3
1886	6	10½	6	3
1887	7	7½	6	7
1888	7	5½	6	7½
1889	8	8	7	3
1890	10	10	8	0

CHAPTER V.

RENTS, ROYALTIES, WAYLEAVES, ETC.

THE terms and conditions of leases are so varied in different districts that only a few of them can be noticed here.

TERM OF YEARS FOR WHICH LEASES ARE GRANTED.

Cumberland and Furness. Generally for 21 years.

Cleveland. 21 years and upwards, commonly 42 years.

Lincolnshire. 21 to 99 years.

Staffordshire. Mostly for 21 years, but occasionally up to 60 years.

South Wales. 42 to 99 years.

Cornwall. Usually 21 years.

Scotland. 19 to 31 years.

Antrim. 19 to 21 years, sometimes for 31 years.

RENTS.

Cumberland and Furness. From £100 to £2,000 and upwards, according to character of mine.

Cleveland. Averages about £2 per acre.

Lincolnshire. £1 to £12 per acre; the latter for small areas only.

Cornwall. From £5 to £50, usually.

Antrim. About 6*s*. or 7*s*. per acre.

ROYALTIES.

Cumberland. Usually one-sixth of selling price at pit's mouth, with a minimum of *2s.* This, however, has been found to be oppressive when prices are low, and some recent leases have been granted with a minimum of *1s.*, the complete scale in these new leases being as under :—

When the selling price is

	s. d.		s. d.			s. d.	
	9 0	and under ...	...	the royalty is		1 0	per ton.
exceeding	9 0	but not exceeding	12 0	„	„	1 6	„
„	12 0	„ „	15 0	„	„	$\frac{1}{6}$	of selling price.
„	15 0	„ „	20 0	„	„	$\frac{1}{5}$	„ „
„	20 0			„	„	$\frac{1}{4}$	„ „

The average royalty in these leases is about one-sixth, but they are easier at the lower end of the scale than the older leases, whilst the lessor obtains a larger proportion when prices are high than he did by the original sliding scale of one-sixth.

Furness. The royalties here are all on the sliding scale; the following, perhaps, being an average :—

When the selling price

	s. d.			s. d.			s. d.	
			does not exceed	9 0	per ton, the royalty is		1 0	per ton.
exceeds	9 0	but	„ „	9 6	„	„	1 1	„
„	9 6	„	„ „	10 0	„	„	1 2	„
„	10 0	„	„ „	10 6	„	„	1 4	„
„	10 6	„	„ „	11 0	„	„	1 6	„
„	11 0	„	„ „	11 6	„	„	1 8	„
„	11 6	„	„ „	12 0	„	„	2 0	„
„	12 0	„	„ „	12 6	„	„	2 2	„
„	12 6	„	„ „	13 0	„	„	2 4	„
„	13 0	„	„ „	13 6	„	„	2 6	„
„	13 6	„	„ „	14 0	„	„	2 8	„
„	14 0	„	„ „	14 6	„	„	2 10	„
„	14 6	„	„ „	15 0	„	„	3 0	„
„	15 0	„	„ „	15 6	„	„	3 3	„
„	15 6	„	„ „	16 0	„	„	3 6	„
„	16 0	„	„ „	16 6	„	„	3 9	„
„	16 6	„	„ „	17 0	„	„	4 0	„
„	17 0	„	„ „	17 6	„	„	4 3	„
„	17 6	„	„ „	18 0	„	„	4 6	„

and for every 6*d.* or portion of 6*d.* in value beyond 18*s.* a ton, an additional royalty of 3*d.* over and above 4*s.* 6*d.* is charged.

Lately it has been found necessary to reduce this scale, especially at the lower prices, so that in some new leases we have the following :—

When the value of the ore delivered into trucks at the nearest railway station

	s.	d.			s.	d.				
is	5	0	per ton and under		6	0	the royalty is	$\frac{1}{18}$th		
"	6	0	"	"	7	0	" "	$\frac{1}{16}$th		
"	7	0	"	"	8	0	" "	$\frac{1}{14}$th		
"	8	0	"	"	9	0	" "	$\frac{1}{12}$th		
"	9	0	"	"			a royalty of 11*d.* per ton.			
								s.	d.	
exceeds	9	0	but does not exceed		9	6	the royalty is	1	0	"
"	9	6	"	"	10	0	"	1	1	"
"	10	0	"	"	10	6	"	1	3	"
"	10	6	"	"	11	0	"	1	5	"
"	11	0	"	"	11	6	"	1	7	"
"	11	6	"	"	12	0	"	1	9	"
"	12	0	"	"	12	6	"	1	11	"
"	12	6	"	"	13	0	"	2	1	"
"	13	0	"	"	13	6	"	2	3	"
"	13	6	"	"	14	0	"	2	5	"
"	14	0	"	"	14	6	"	2	7	"
"	14	6	"	"	15	0	"	2	9	"
"	15	0	"	"	15	6	"	3	0	"
"	15	6	"	"	16	0	"	3	3	"
"	16	0	"	"	16	6	"	3	6	"
"	16	6	"	"	17	0	"	3	9	"
"	17	0	"	"	17	6	"	4	0	"
"	17	6	"	"	18	0	"	4	3	"
"	18	0	"	"	18	6	"	4	6	"
"	18	6	"	"	19	0	"	4	9	"
"	19	0	"	"	19	6	"	5	0	"
"	19	6	"	"	20	0	"	5	3	"

and for every 6*d.* or portion of 6*d.* in value beyond 20*s.* a ton, an additional royalty of 3*d.* over and above 5*s.* 3*d.* is charged.

Cleveland. From 4*d.* to 1*s.* 2*d.* per ton; average about 6*d.*

Lincolnshire. From 6*d.* to 1*s.* per ton; average about 8*d.*

Northamptonshire. From $2\frac{1}{2}d.$ to $6d.$ per ton; average about $4d.$

South Staffordshire. From $9d.$ to $1s.$ $6d.$ per ton; average about $1s.$

South Wales for coal-measure ironstone. From $6d.$ to $1s.$ per ton, average about $8d.$

South Wales for limonite. From $8d.$ to $1s.$ per ton; average about $8\frac{1}{2}d.$

Scotland for blackband. From $1s.$ to $2s.$ $6d.$ per ton, average about $1s.$ $6d.$

Scotland for clayband. From $3d.$ to $1s.$ $6d.$ per ton; average about $6d.$, or sometimes on sliding scale ranging from $\frac{1}{12}$ to $\frac{1}{8}$ of selling price at pit's head.

Antrim. From $3d.$ to $6d.$ per ton; average about $4d.$

Bilbao. From $0d.$ to $2s.$ per ton; average about $1s.$

WAYLEAVES.

Cumberland. Usually $1d.$ to $2d.$ per ton for underground, and $1d.$ per ton for surface.

Furness. Usually $1d.$ per ton for underground and surface.

Cleveland. Usually $1d.$ per ton for underground and surface.

Scotland. $1d.$ to $3d.$ per ton for underground; surface, usually $1d.$

PERIODS FOR MAKING UP "SHORTS."

Cumberland. Usually triennial periods, but occasionally longer, as well as shorter, periods are granted.

Furness. Similar to Cumberland.

Cleveland. Usually over the whole term, but sometimes limited to 5 or 7 years.

Lincolnshire. 4 to 14 years.

Scotland. 1 to 3 years.

Antrim. In the following or two following years.

Following are excerpts from two leases, that will show the general conditions under which iron ore is worked in different parts of the country.

EPITOME OF LEASE OF IRON ORE IN CUMBERLAND.

Mines, veins, etc., of ore, etc., to be demised.

THE lessors demise to the lessees all the mines, veins, seams, or beds of iron ore, ironstone, minerals, and mineral substances, belonging to the said lessors, as well opened as unopened, lying, and being in or under, all the several closes, inclosures, or parcels of land of the said lessors situated in —— and delineated on the plan annexed to this lease.

Lessees to have liberty to enter lands to search for and work minerals.

Lessees to have full and free liberty to enter upon the said lands and search for the mines, veins, beds, and seams of iron ore, ironstone, minerals, and mineral substances, and dig and raise such of the same as shall be there found, and to stack and deposit the same, when raised, in heap-rooms in or upon any part of the said grounds, and to carry away and dispose of all the said ore and minerals which may be so found and produced.

Lessees to have liberty to construct works, etc.

Lessees to have liberty to construct all works or other conveniences for making the ores merchantable, and to sink, drive, make, erect, repair, and use all such pits, shafts, adits, levels, drifts, sumps, headways, water-courses, airgates, passages, steam-engines, breaks, gins, and other machinery and works as may be found necessary for working the mines and for draining and discharging the water therefrom and supplying the same with pure air and freeing the same from impure air in the best and most efficient and mining-like manner.

Lessees to have liberty to construct railways, etc.

Lessees to have liberty to construct railways, tramways, carriage, and other ways on said land, subject first to the approval in writing of the lessors or their agent.

Lessors reserve sufficient pillars for support of pits and shafts.

The lessors reserve to themselves so much and such parts of the said mines, etc., as they or their authorised agent shall consider necessary to be left for the support of all such pits and shafts already sunk or hereafter to be sunk, or for the proper working of them.

Term twenty-one years.

Lessees to have and to hold the said mines, etc., for the term of twenty-one years, subject to the statutory rights of the owners of the —— railway in respect to such of the mines and premises hereby demised as lie under the same or within forty yards therefrom.

Rent.

Lessees to pay a yearly rent of £250 for first, second, and third years, and £500 per year for remainder of term, payable half yearly, and to be at liberty to raise, for such yearly rents, such a quantity of iron ore or ironstone as at the royalty rates hereafter mentioned would amount to said certain yearly rent.

Royalty.

Lessees to pay following royalty for every ton of 2,240 lbs. of iron ore or ironstone raised—viz.,

When the selling price at pit's mouth shall be under fifteen shillings per ton, royalty to be one-sixth of same. When such value shall be fifteen shillings and not exceeding twenty-four shillings per ton, royalty to be one-fifth of same. When such value shall exceed twenty-four shillings per ton, royalty to be one-fourth of same.

Royalty for other minerals than Iron Ore or Ironstone.

Lessees also to pay for all other minerals and mineral substances whatsoever (other than iron ore or ironstone) one-tenth of the selling value of same.

Wayleave.

Lessees to pay for wayleave twopence per ton for all iron ore and other minerals brought to surface from other mines, through or by means of the mines hereby demised, or led or carried over surface of said mines.

Method of making up short workings.

Lessees to have privilege, in case at any time they should not have raised a sufficient quantity of minerals as at the tonnage rents hereinbefore mentioned would produce the certain rent hereinbefore reserved, of making up such shorts, in manner following:—

For any year within the period of the first six years, or of the next, or of any subsequent consecutive period of three years,

the lessees may in the next year or years of said periods, raise such a quantity of mineral as would make up the deficiency without paying any royalty in respect thereof, and any short workings not made up in this way or which shall happen in last year of term shall not be allowed.

Definition of selling price. The selling price shall be the price at the point of delivery on the public railway, less twopence per ton for haulage and expense of delivery from pit's mouth.

Surface damages. The lessees to pay £2 per acre for every acre of the said mineral grounds held, used, or occupied by them or injured or damaged by mining operations and not restored for agricultural purposes.

Ore, etc., raised outside of boundaries. The lessees to yield and render to the lessors all iron or ironstone, etc., which without the previous consent in writing of the said lessors shall be raised out of the said mineral grounds by means of pits or shafts made or sunk outside the boundaries of said mineral ground.

Deductions allowed off rents. The said rents to be paid clear of all deductions except landlord's income tax.

Distraint for arrears of rent. In case the said rents, or any part thereof, be in arrear for twenty-eight days, lessors to have power to make distraint upon the said mines, ore, plant, etc.

Rates and taxes. Lessees to pay all existing and future taxes, rates, assessments, etc., except landlord's income tax.

Land damages. Lessees to pay £240 per acre for all lands, the surface of which shall have been broken, damaged, or permanently destroyed by being taken or used for the purpose of the said mines; but if at the end of the term lessees shall restore any such land, paid for after this rate, to as good a condition as when they first took possession, they shall be entitled to be repaid such sum as under this clause shall have been paid in respect thereof.

Tenant's damages, etc. Lessees to make sufficient compensation to the tenant or occupier in possession of the said mineral grounds for any injury or damage which may be done to the crops growing on the lands, and also in addition the sum of £4 per acre, and also pay all other damages of whatsoever description, and to whomsoever payable, occasioned by their operations.

Mines not to be assigned or underlet. Lessees not to assign or underlet the mines, or any part thereof, without previous consent, in writing, of the lessors.

Weighing machines. The lessees to keep proper weighing machines for weighing the minerals.

Half-yearly royalty statements. The lessees to deliver to the lessors half-yearly statements of all the minerals raised during such half year.

Monthly royalty statements. The lessees to deliver monthly statements of all minerals raised during such month, with full particulars as to destination, price, etc.

Books. The lessees to keep proper books, in which are to be entered full particulars of all minerals raised from the mines, and also of all minerals conveyed therefrom for sale or shipment, and permit the lessors to inspect same at any reasonable time.

Plans and Boring Journal. The lessees to keep correct maps and plans of the mines, workings, etc., and also a journal containing an account of all borings and sinkings, which are to be made up quarterly, and produced on demand to the lessors.

Fencing. The lessees to effectually fence off such part or parts of the mineral grounds as they may dig open or use, and provide gates where necessary for the convenient occupation of the adjoining lands, and provide sufficient and convenient communication over and across every road and way made by virtue of the powers hereby granted, for the use of the occupiers of the adjoining lands, so that the severance of such lands may cause as little inconvenience as may be to the occupiers thereof.

Mines to be worked vigorously and skilfully. The lessees at all times to work the mines vigorously and uninterruptedly in a proper and mining-like manner, and according to the most approved practice of mining, and in such manner as to get and raise the greatest quantity of iron and ironstone which can reasonably be gotten from the same.

Damages for unskilful working of mines. If by any unskilfulness or careless management, any of the mines, beds, veins, seams, or bands of ore or other minerals, be rendered incapable of being worked, the ore and minerals therein shall be paid for by the lessees as if the same had been actually gotten by them.

Mines not to be worked from pits outside of boundaries.

The lessees not to work the said mines, beds, etc., from any pits outside the boundaries of the said mineral grounds without the consent in writing of the lessors, and not to work any mines, beds, etc., other than those hereby demised, from any pit within the last-named boundaries, without the previous consent in writing of the lessors.

Pillars near shafts.

The lessees not to remove or split any pillars of ore, etc., within fifty yards from any main shaft, without giving lessors twenty-eight days' previous notice in writing of their intention to remove or split the same.

Shafts to be kept in proper repair.

The lessees to keep in good repair all shafts sunk which may be necessary for the proper working of the mines, beds, etc.

Earth and soil to be laid aside.

The lessees to lay aside, in heaps, all the earth and soil which shall be dug up and raised in working the said mines.

Lessees not to do any wilful or negligent act endangering mines, etc.

The lessees not to do or suffer to be done, at any time, any wilful or negligent act, matter, or thing which may hazard, endanger, or occasion loss or damage to the said mines, beds, etc., of ore or other minerals.

Inspection by lessors.

Lessors or their agents, at all reasonable times, to have power to inspect the said mines and to survey the same, and to have the assistance of the lessees' workmen and agents for this purpose.

Adjoining mines.

If the lessees are now, or if during the said term they shall become owners, lessees, or occupiers of any adjoining mines or royalty, and any dispute shall arise between the said lessors and the said lessees touching the boundary of the mines hereinbefore demised, and such adjoining mines or royalty or any subsidence, either on the surface or underground, alleged by the said lessors to have been caused by the workings of any such adjoining mines; or if any matter of difference arising out of the contiguity of the two adjoining mines shall arise, then the said lessees shall, if required, permit the said lessors, or their agent, to enter, survey, and inspect the workings of such adjoining mines or royalty in the same manner as hereinbefore provided for, in respect of the mines, etc., hereby demised. The lessees to produce for inspection all plans, papers, etc., which may be necessary, in the opinion of the lessors, to the settlement of such dispute or difference.

Lessees to give up possession at determination of term.

Lessees at expiration or sooner determination of said term to deliver up to the said lessors the mines, beds, veins, etc., hereby demised, together with all ore and minerals, which at the end of three calendar months after such expiration shall be on the said mineral grounds. And also all erections and buildings (except such as the said lessees are hereafter authorised to remove and shall remove), in as good a state and condition as the nature of the case will admit of.

Lessees may remove plant at end of term.

Proviso. That the said lessees may at any time within three calendar months after the expiration of the said term, take down, remove, and convert to their own use the materials of all such engines, plant, machinery, rails, and works (except as hereinafter mentioned), as now are, or shall have been erected or made upon or under the said mineral grounds, but except so far as may be necessary for the removal of any engines or machinery thereon, the said lessees shall not be at liberty to remove, or pull down wholly or partially any buildings of brick or stone, which now are or hereafter during the said term may be erected on the said mineral grounds.

Liberty for lessors to purchase plant at end of term.

Proviso. That in case the said lessors shall before the expiration of the said term be desirous of purchasing any of the engines, plant, machinery, etc., in or about the mines, and shall give three calendar months' previous notice in writing of such desire, then the said lessees shall deliver up to the said lessors such of the said things as shall be so required, the said lessors paying for the purchase thereof.

Power of re-entry for lessors if mines not worked properly.

Proviso. That if the lessees shall at any time not work the mines regularly, or be found upon an arbitration, to be conducted as hereinafter provided, to be working or using the said mines in an improper, unskilful, or unmining-like manner, lessors to have power of re-entry until full satisfaction is made for all loss or damage which may have been occasioned thereby, and in this case lessees not to have privilege of making up any shorts arising during time of re-entry and possession by lessors.

Re-entry by lessors in case of arrears of rent, etc.

Proviso. That lessors have power of re-entry and of determining lease if any of the rents are in arrear for thirty days or if the lessees return any fraudulent or false accounts, or commit any breach of the covenants and agreements herein contained.

Breaks for determining lease. Proviso. That lessees may at the end of the third, sixth, ninth, twelfth, fifteenth, or eighteenth years of the said term determine same by giving not less than one year's previous notice in writing.

Arbitration. Usual arbitration clause in case of any difference arising between lessors and lessees concerning any matter in connection with this lease.

Lessees not entitled to have any rents refunded. Proviso. That lessees will not be entitled to ask for, demand, sue for, claim, or recover from the lessors any rents paid by them to lessors notwithstanding the claim, right, or title of any other person whatsoever to any of the mines, beds, etc., hereby demised.

Lessees to keep lessors indemnified against all actions, etc. Lessees to keep lessors indemnified from and against all actions, suits, costs, claims, and demands whatsoever, by any person or persons, for or in respect of any mines, beds, etc., which shall be worked, raised, or carried away or disposed of by the lessees or any other person or persons whatsoever, under, or by virtue, or under the authority of these presents.

EPITOME OF LEASE OF IRON ORE IN LINCOLNSHIRE.

Extent. THE lessors demise all the mines, veins, seams, beds, rakes, and quarries of ironstone and iron ore opened and unopened in —— acres, in ——, Lincolnshire, as set out in plan.

Not to work near buildings. Liberty for lessees to enter lands not being within one hundred yards of any house, etc.

Lessees to give notice before taking land. Lessees to give one month's notice to tenant before taking land and make compensation for tenant right, etc.

Liberty to work mines. Liberty for lessees to raise, get and work mines, veins, etc., and to sink shafts not within one hundred yards of any house, etc., and to drive, make, and erect gates, adits, engines, etc.

Liberty to erect Blast Furnaces, etc. Liberty for lessees to stack ironstone, etc., raised on land, and to erect blast furnaces, etc., to get stone, brick-earth, etc., for making bricks, etc., for the works but not for sale, and also to make railways, etc., the same to be sanctioned by lessors.

Liberty of ingress. Liberty of ingress, egress, and regress for lessees, and to use all pits, etc., already sunk.

Lessors reserve power to work other mines, etc. Reservation to lessors of rights to work other mines, but so as not to interfere with lessees, also of mines, etc., under any houses, also to make roads, tramways, etc., intersecting roads, etc., to be made by the lessees, the lessors making compensation for wear and tear.

Term. Term sixty-three years from —— 18—.

Rents. £500 yearly rent during first three years of said term. £1,000 per annum during residue of term.

Quantity of ore to be raised for rent. As an equivalent for said rents lessees may raise such quantity which, during said respective periods of years and at rates therein mentioned, should amount to or be equivalent to the said respective standing yearly rents, or sum of £500 and £1,000 subject yearly during first period of twenty-one years.

Royalties. Eightpence per ton of 2,400 lbs. during first three years of said term for such quantity as should amount to the said rent of £500, and during the eighteen years as should amount to said rent of £1,000. And yearly during the next period of twenty-one years as shall at the rate of tenpence per ton amount to £1,000 yearly. And yearly during residue of said term as at one shilling per ton should amount to said yearly rent of £1,000.

Eightpence per ton during the first twenty-one years for all ironstone and ore over and above the quantity it shall be lawful to raise in respect of the said fixed rents of £500 and £1,000.

Tenpence per ton during the next period of twenty-one years for all ironstone raised over and above the quantity in respect of the said yearly rent of £1,000.

One shilling per ton during residue of term for any quantity over and above the quantity in respect of the said yearly rent of £1000.

Threepence per ton for all limestone.

Four years to make up shorts. If in any year the quantity of ironstone and iron ore shall not be of such a quantity as shall at the aforesaid rent be equivalent to amount of said certain rent, then and in such case it should be lawful for lessees in any of the four next succeeding years of said term to make up such deficiency out of said demised mines without paying any rent or sum of money for the same, other than or beyond the said certain yearly rent payable in each of the said four years, so nevertheless, that surplus workings of any preceding years of said term shall not be allowed to come in aid of or make good the deficiency of the workings in any following year or years, but the respective rents hereby reserved in respect of such overworkings are to be paid when and as the same shall become due and payable.

Distress. Proviso. If rents unpaid for twenty-eight days after they become due and after demand, lessors to be at liberty to distrain on all the effects and dispose of distress.

Re-entry. Proviso. If rents unpaid for sixty days, or lessees assign without consent or become bankrupt, etc., lessors may re-enter and determine demise.

Lessees to pay rates and taxes. Covenant by lessees to pay rates and taxes, except landlord's property tax, and pay yearly rent of £4 per acre to tenants of land on ——, and the yearly rent of £6 for every acre of land on ——.

Rent of land occupied.

Mines to be worked properly. Lessees to work mines in a proper manner, according to most approved method.

Not to work by outstroke or instroke. Lessees not to work the mines demised by outstroke, instroke, etc., from any adjoining mines.

No impediments. Lessees to do nothing to impede working of mines.

Lessor's inspectors. Lessees to convey free of charge all inspectors on behalf of lessors, to examine workings with two overmen if necessary.

Objections to mode of working. If any fault be found in the working, lessees to put same right within thirty days, and in default lessors to do what is necessary, and charge expense to lessees with interest.

Weighing machines. Lessees to provide and keep proper weighing machines, and to cause all ironstone to be weighed before leaving premises.

Books of account. Lessees to keep proper books of account of all the iron, etc., raised, gotten, sold, etc.; and within fifteen days of the first of every month deliver a statement to lessors of the iron ore, etc., raised during the preceding month; also a proper account of the ironstone, etc., sold during the previous month; and also make out similar half-yearly statements for the tonnage rents.

Plans. Lessees to keep proper plans showing workings.

Half-yearly surveys. Lessees to make admeasurement of the workings for the preceding half year.

No unnecessary damage. Also shall not commit any unnecessary damage carrying on the works.

Severance of land, etc. Also in all cases where the surface of the lands shall be severed by any road, etc., so far as may be necessary shall restore same at their own expense, and shall restore gates and crossings where any communication cut off, and also such waterways crossing the rivers, and the meadows adjacent thereto.

Repairs. Also keep all gates to be made as aforesaid in good order and condition.

Also will maintain all culverts, waterways, etc.

Tenants' damages. Also will make all reasonable compensation to tenants for damage to growing crops.

Damage to buildings. Also will make good and restore any damage which may be done to any buildings.

Land taken to be fenced. Also will fence off all land taken possession of for the purpose of the mining operations.

Restoration of surface. And also after the lessees have exhausted the ironstone from any part of the appropriated lands, or after they have ceased for six months to use the same, shall before —— day of —— in each year fill up all pits or shafts, surface, and quarry excavations so far as practicable, and shall, to the satisfaction of the lessors or their agent, cover the same with good soil like the surrounding land to the depth of eighteen inches at the least, and so as to make the said lands fit for ploughing, tillage, and cultivation in the best possible manner, making and restoring the ground as near to the state of the adjoining lands as circumstances will permit.

Also when any furnaces, buildings, etc., shall be removed, will level the site to the depth aforesaid, but no rent shall be payable after the lessees cease to work the lands so restored as aforesaid.

Soil and turf to be preserved. Also will before making any pit, shaft, etc., and before slacking any ironstone, etc., pare and carry away all the turf and soil to the depth it now is, and preserve the same until again needed.

Not to work near any house. Also will not work the mines, etc., or break the surface within one hundred yards of any house.

Also will not permit miners, etc., to enter upon unappropriated lands.

Not to assign. Also will not assign, etc., lease, etc., without consent of lessors.

Partner. Provided that the introduction of a partner into the Company should not be a breach of the last covenant, but the name of every new partner to be given to lessors, and a certified list of partners to be given when required.

Lessees not to bring upon or over the lands, railways, etc., any ironstone, etc., from other mines except for exclusive use of lessees.

To give up possession. Lessees to deliver up quiet possession to lessors at end or sooner determination of term, and to make good and restore all hedges, etc., that may have been cut through or removed, and fill in all pits, etc., and level all mounds and embankments to make surface level with adjoining land, and remove rubbish, etc., but lessors first to have option to allow lands to remain in same state, and compensate lessees therefor.

Time allowed for removal of buildings, etc. Proviso. The lessees may, within six months after end of term, having satisfied covenants, etc., take and use ironstone, etc., raised and standing on the land, and remove houses and other erections built with timber; buildings of brick or stone to be left for lessors without compensation.

Lessors may purchase plant. Proviso. If lessors are desirous of purchasing any of the erections, plant, etc., upon ground at end of term, they to give notice within one month after end of term. Price to be settled by arbitration in case of dispute.

Failure of mines. Proviso. If mines, etc., fail, or be completely exhausted, etc., the lessees may, if they so desire, yield up the same on any half-yearly day on giving three months' notice. Any question as to failure, exhaustion, etc., to be determined by arbitration.

Determination of lease. Lessees may also give up the premises at end of any year on six months' notice.

Furnaces to be built. Lease is granted on the condition that the lessees will, before —— day of —— 18—, erect two good blast furnaces for smelting iron ore, etc., hereby demised, also iron ore, if desired, raised from —— estate, also leased to lessees, and from lands within three miles of boundary of lands demised.

Proviso. If lessees make default in erecting aforesaid furnaces, the term of sixty-three years shall be reduced to forty-two years.

If lessees erect four furnaces on —— estate they shall be accepted for and in lieu of the two furnaces herein provided for.

Arbitration. Arbitration clause.

Notices. Provision as to giving notices.

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